Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

Reserve
aS21
.A75U45

Proceedings

WHEY PRODUCTS CONFERENCE

held at Atlantic City, N.J.
October 14-15, 1976
and sponsored jointly by
The Whey Products Institute
and
The U.S. Department of Agriculture

ARS-NE-81
APRIL 1977

EASTERN REGIONAL
RESEARCH CENTER

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

Proceedings

WHEY PRODUCTS CONFERENCE/1976

held at

Atlantic City, New Jersey

October 14-15, 1976

sponsored jointly by

WHEY PRODUCTS INSTITUTE
Chicago, IL 60606

and

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Research Service
Eastern Regional Research Center
Philadelphia, PA 19118

Statements made in the papers are the speakers' own and do not necessarily represent the views of the U.S. Department of Agriculture. References, figures, and tables are reproduced essentially as they were supplied by the speakers. Numbers in parentheses refer to references at end of each paper. Mention of commercial products does not imply recommendation by the U.S. Department of Agriculture.

Additional copies of these proceedings are available from:

Eastern Regional Research Center
Agricultural Research Service
U. S. Department of Agriculture
600 East Mermaid Lane
Philadelphia, Pennsylvania 19118

April 1977

PROGRAM AND CONTENTS

Thursday Morning, October 14

Session Chairman: J. H. Woychik
Eastern Regional Research Center

Page

Welcoming Remarks:
  N. van Zwanenberg 1
  I. A. Wolff 1

Major Whey Products Markets--1975 - W. S. Clark. 4

Which Way Whey? - T. F. Graf 9

Thursday Afternoon, October 14

Session Chairman: M. J. Pallansch
Marketing Nutrition and Engineering Sciences

Electromembrane Technology for Whey Processing - R. M. Ahlgren 27

Advances in Ultrafiltration Processing Technology as Related to Applications in the Dairy Industry - B. R. Breslau 37

Adaption of UF to Whey Processsing - O. J. Olsen 61

Sanitary Considerations Involved with Ultrafiltration Equipment - R. G. Semerad. 69

Whey Dehydration Process - T. Silverman. 76

Friday Morning, October 15

Session Chairman: J. M. Dunker
Dairyland Products, Inc.

Utilization of Whey as a Human Food - K. M. Shahani. 84

Utilizing Whey as an Animal Feedstuff - J. W. Juengst, Jr. 94

New Uses for Lactose - F. W. Parrish 104

Session Chairman: C. H. Roach
Foremost Foods Company

Progress in International Dairy Federation Whey Programs - B. H. Blanc .115

Australian Whey Research Programs - L. L. Muller 119

Whey Processing in New Zealand - K. R. Marshall. 129

WELCOMING REMARKS

N. van ZWANENBERG

President, Whey Products Institute
Cuba Cheese and Trading Co., Inc.
Cuba, NY 14727

I. A. WOLFF

Director, Eastern Regional Research Center
Agricultural Research Service, USDA
Philadelphia, PA 19118

Mr. van Zwanenberg:

As President of the Whey Products Institute, one of the cosponsors of this conference, and on behalf of the U.S. Whey Processing Industry, I join Ivan Wolff of the Eastern Regional Research Center, USDA, the other conference cosponsor, in welcoming you to the 1976 Whey Products Conference. This is the fourth in a series of whey conferences held every two years since 1970 when the first conference was held at the University of Maryland, College Park. The second and third conferences were held in Chicago, IL, in 1972 and 1974. Interest has remained high as evidenced by the large number of attendants at this year's conference.

This year's conference has four major discussion areas: (1) economic and marketing aspects of the U.S. Whey Industry; (2) advances in whey processing techniques; (3) whey utilization through product development; and (4) a look at whey developments and research worldwide. We especially welcome the many conference attendees from outside the continental United States.

Dr. Wolff:

Since this is now the Fourth Biennial Whey Products Conference, we can begin to achieve some historical perspective. At the first conference (1970), the theme of one session posed the rhetorical question, "Pollution or Utilization?" Membrane processing was at that time a fledgling with much maturation needed. Whey properties, composition, processing, and uses were reviewed in terms that today might be considered rather elementary. At the second conference (1972), one of our speakers struck a proper keynote in proclaiming, "Whey is becoming an increasingly important stepchild of the dairy industry." Already, in those two years between the first and second conferences, significant progress could be reported in both whey processing and whey uses. At the third conference (1974), then President of the Whey Products Institute, Mr. Proctor, said "...When we consider utilization, we look forward to the tremendous opportunities we have for continued growth in this area. The future of our whey industry, in my opinion, is a very dynamic one." The statement reflects maturation and growth in an already established and recognized field. On October 14, 1976, I say that he was a true prophet. Today when we scan the pages of food industry trade publications, we see four-color page spreads advertising modified whey solids products. Wheys have taken their place as mature members among the food formulator's ingredients of choice and are bringing functional and nutritional benefits to traditional and newly engineered food products.

We in the USDA's Agricultural Research Service are proud that we have shared with the Whey Products Institute and its participating member companies, with universities, and with other public agencies, an exciting role in pioneering this progress that has taken place since 1970. The subject of whey processing and utilization has achieved so great an importance and stature that this is only one forum for discussions on whey. Recent national meetings of the American Chemical Society, Institute of Food Technologists, and the American Dairy Science Association have featured technical presentations of results in specific areas of whey research. In 1975 the National Science Foundation sponsored a workshop, with limited attendance, for reviewing whey research problems and priorities among attendants from the United States, Australia, New Zealand, Canada, and Ireland. There are also other avenues for publication and presentation of information on whey.

These whey product conferences, by continuing to focus attention on the topic, can bring together in a unique way an interchange of information and ideas of those with a vital interest in the future of whey. We will discuss some significant accomplishments, report on developments underway, and chart research that will continue the growth of whey in tomorrow's markets--both food and nonfood.

The laboratory experiments of yesterday are new technologies now. Foods on the grocery shelf are better for the inclusion of whey products from processes never before commercialized. The everenlarging use of membrane processing offers a variety of whey protein concentrates having good nutritional and organoleptic quality. Modified whey solids, protein concentrates, and dried whey in many forms improve the quality of foods ranging from fortified beverages to bakery products and have high potential in such areas as sausage products and ice cream mixes. Research now underway points to even more versatile whey modifications on tomorrow's markets at higher recovery and yield levels. Whey from lactase modifications promises quality and economy in cheesemaking, together with new uses for the released monosaccharides. Technology of acid or enzymatic lactose hydrolysis provides opportunity for utilization as sirups in a variety of foods and for the prevention of crystallization in confections. Hydrolyzed lactose wheys offer a fermentable energy source to organisms unable to utilize lactose, thereby broadening potentials for fermentative utilization. Lactose itself is being viewed in a fresh light--as a chemical precursor for a variety of food and nonfood products. New developments in areas of solventless reaction chemistry suggest new approaches in the fields of surfactants, noncaloric sweeteners, and a variety of lactose-derived compounds.

Beyond today's work in the laboratories of government, academia, and industry lie further advances. We can sense a day when abundant whey will be modified by biosynthesis into protein foods with more of the functionality of casein, egg white, and wheat gluten. The saccharides in whey will give us new sources for direct food uses and, by modification, new derivatives to replace petrochemical counterparts in detergents, plastics and many synthesized compounds. Yet so recently we began at negative, when nearly all whey was discard now the turnaround of whey, a replenishable resource, represents a sound scientific and technological achievement.

With a special welcome to participants and guests from outside the United States, I express my confidence that the interchange of ideas among all the experts and of all disciplines in the formal sessions and in the corridor conversations will catalyze some new initiatives in further improving whey utilization.

MAJOR WHEY PRODUCTS MARKETS--1975

W. S. CLARK, JR.

Executive Director, Whey Products Institute
Chicago, IL 60606

WHEY PRODUCTION

Since organization of the Whey Products Institute (WPI) in 1971, we have estimated yearly figures representative of total U.S. fluid whey production, corresponding equivalent whey solids, and the percentage of these whey solids which were "further processed" into products either for human food or for animal feed. Our estimates were based upon cheese production and so fluid whey and whey solids are referred to by type--sweet-type coming from cheddarlike cheeses and acid-type obtained from cottage cheese. A summary of these figures is shown in Table I.

In comparing U.S. fluid whey and whey solids production, as estimated by WPI, for the years 1974 and 1975, total production of fluid whey for 1974 was estimated at 30.5 billion pounds, with the following breakdown: 26.4 billion pounds of sweet-type; 4.1 billion pounds of acid-type, and for 1975, was estimated at 29.5 billion pounds, with the following breakdown: 25.3 billion pounds of sweet-type; 4.2 billion pounds of acid-type. Further, the 30.5 billion pounds of fluid whey for 1974 and the 29.5 billion pounds of fluid whey for 1975 are both equivalent to approximately 1.9 billion pounds of whey solids.

In 1975, supported by a grant from the WPI, the Statistical Reporting Service, USDA, began collecting production figures representative of whey solids production with have been tabulated as follows:

CONDENSED WHEY, SOLIDS CONTENT PRODUCTION

Sweet-type:	
Human Food	74,897,000
Animal Feed	5,674,000
Acid-type:	
Human Food	8,697,000
Animal Feed	4,095,000

DRY WHEY PRODUCTS PRODUCTION

Dry Whey:	
Human Food	412,992,000
Animal Feed	147,485,000
Partially Delactosed:	
Human Food	24,459,000
Animal Feed	123,277,000

Partially Demineralized:	
Human Food	22,320,000
Animal Feed	2,371,000
Partially Delactosed/Demineralized:	
Human Food	5,077,000
Animal Feed	1,802,000
Lactose:	
Human Food	108,108,000
Animal Feed	29,476,000
Whey Solids in Wet Blends:	
Human Food	23,382,000
Animal Feed	56,577,000

USE OF WHEY PRODUCTS

In 1975 the Whey Products Institute conducted its first annual "Survey of Whey Products Utilization and Production Trends." The survey included WPI members and other cooperating manufacturers/processors plus additional data obtained from responses by distributors/re-sellers of whey products. Slightly over 50 percent responded to the survey. Bearing in mind that this was an initial survey including a number of various types of whey products, in many utilizations, we therefore were gratified with the percentage participation.

We are certain that ensuing annual whey products surveys will develop increasing participation by industry as well as by distributors/re-sellers, resulting in improved information on markets of utilization.

Again, remember that data reported in Tables II, III, and IV are actual figures reported in the WPI census and do not reflect total whey usage in the respective market categories.

These data on the major U.S. whey products markets were assembled by Henry Paul, our Institute Statistician. I will be pleased to attempt to answer any questions, however, not having been directly involved with compilation of the raw data furnished, my answer or comment may not be as extensive as if Mr. Paul were present.

TABLE I.--Estimated U.S. fluid whey and whey solids production (by type) and resulting quantity of whey solids "further processed"

ITEM	Billions of pounds of whey in-- 1972	1973	1974	1975
Sweet-type whey:				
Cheese production[1]	2,605	2,685	2,930	2,811
Calculated fluid whey[2]	23,445	24,165	26,370	25,299
Calculated whey solids[3]	1,524	1,571	1,714	1,645
Acid-type whey:				
Cottage cheese production	784	763	687	701
Calculated fluid whey	4,704	4,578	4,122	4,206
Calculated whey solids	306	297	268	273
Total fluid whey production	28,149	28,743	30,492	29,505
Total equivalent whey solids (Sweet-type + acid-type)	1,830	1,868	1,982	1,918
Percentage of total whey solids utilized				
$\frac{\text{Total whey solids manufacture}}{\text{Total equivalent whey solids}} \times 100$	53.2	55.0	56.7	60.1

---

[1] USDA, Crop Reporting Board, SRS, - Da 2-1.

[2] Whey Production: Approximately 9 lbs/1 lb cheese produced (except cottage)
approximately 6 lbs/1 lb cottage cheese produced.

[3] Average percentage of total solids content of whey, 6.5.

Table II.--1975 End-uses of whey solids for human food

Use	Millions of pounds of-- Sweet-type	Millions of pounds of-- Acid-type
DRY WHEY		
Bakery	82.7	2.0
Blends	26.7	.5
Dairy	92.0	.2
Meat processing	.6	.1
Confectionery	6.5	-
Soft drinks	.5	-
Prepared dry mixes	16.2	.1
Soups	1.2	-
Margarine	1.1	-
Institutions	.1	-
All others	5.5	.4
Total	233.1	3.3
CONDENSED WHEY SOLIDS		
Bakery	3.5	2.2
Dairy	4.5	-
Confectionery	.5	-
Prepared dry mixes	2.6	-
All others	71.0	1.5
Total	82.1	3.7
MODIFIED WHEY PRODUCTS		
Bakery	.9	1.6
Dairy	6.2	-
Confectionery	2.4	-
Infant foods	10.8	-
Institutions	-	.1
Prepared dry mixes	3.6	-
All others	.9	.1
Total	24.8	1.8

Table III.--1975 End-uses of lactose

Use	Millions of pounds
Pharmaceuticals	11.7
Infant foods	34.0
Dietetic foods	14.6
Dairy products	7.1
Fruit jellies and jams/preserves	.2
All others	5.8
Total	73.4

Table IV.--1975 End-uses of whey solids for animal feed

Use	Millions of pounds of-- Sweet-type	Millions of pounds of-- Acid-type
Dairy/calf/cattle feeds	162.3	5.6
Poultry feeds	7.9	-
Swine feeds	130.4	-
Pet foods	18.0	-
Other feeds	9.6	.9
Total	328.2	6.5

WHICH WAY WHEY?

T. F. GRAF

University of Wisconsin
Madison, WI 53706

In an industry known for its divergence of opinion, dairymen surprisingly agree on one thing--whey is in trouble, big trouble. Why? Because more whey is being produced than the commercial market can absorb. Does this mean we should all give up and go home? I say no and I think you agree.

My presentation is in two parts: (1) The current whey situation and how did we get there and (2) where do we go from here in trying to solve the problem?

CURRENT WHEY SITUATION

The supply of whey has been growing enormously--much faster than most of us realize. In the past decade, U.S. whey powder production almost doubled--from 404 million poinds in 1965 to 766 in 1975. Meanwhile, production of nonfat dry milk for human consumption was cut in half, dropping from 2 to 1 million pounds between 1965 and 1975 (Table I).

There is now three-fourths as much whey powder as nonfat dry milk powder, compared with one-fifth as much a decade ago. Increasing volumes of whey powder are being processed in a shrinking market for nonfat dry milk--a far more difficult situation for whey than if the market for nonfat dry milk were increasing.

Table I.--Nonfat dry milk and dry whey production, United States, 1965-75

Year	Nonfat dry milk	Dry whey
	Million pounds	
1965	1,989	404
1970	1,444	621
1971	1,418	679
1972	1,223	762
1973	917	772
1974	1,020	851
1975	1,025	766

Source: Dairy Situation, USDA, ERS, DS-361, July 1976 and Dairy Products, SRS, USDA, May 1976.

The volume of liquid whey also increased enormously--by over one-fifth since 1970--to 29.5 billion pounds in 1975. Only 58 percent of the 2 billion pounds of whey solids from this whey was utilized last year, and over one-third of the dry whey was used for animal feed.

There is a lot of whey, its supply is increasing rapidly, and almost one-half of it is not being utilized.

Why has this happened? Because cheese production has skyrocketed. American cheese production increased 43 percent in the past decade to 1.66 billion pounds in 1975, while Italian cheese production increased 269 percent to 658 million pounds. Total hard cheese production jumped 458 percent in the past half century, to 2.8 billion pounds in 1975 (Figure 1). As a result, the volume of milk used in cheese has increased rapidly, almost doubling since 1960; while the volume used in other manufactured dairy products declined (Figure 2). This increase in volume of milk utilized in cheese resulted in accompanying huge increases in volumes of whey.

Why has cheese production increased so rapidly? Because per capita cheese consumption is also up--more than one-half for American cheese, more than double for other cheeses, and more than five-fold for Italian cheese in the past two decades (Figures 3 and 4).

This increase in cheese consumption was accompanied by substantial increases in wholesale cheese prices--approximately 50 percent since 1972 to over 90 cents per pound at present. In this time period, butter and nonfat dry milk prices also went up about one-half to over 90 cents per pound for butter and over 60 cents per pound for nonfat dry milk (Figure 5).

Meanwhile, dry whey prices stayed almost constant, increasing only about 1/2 cent per pound since 1972 to 7-1/2 cents per pound for human grade dry whey in late September 1976. The spread between whey powder prices and nonfat dry milk prices has almost tripled since 1970, from about 20 to 60 cents per pound, pinpointing the whey price problem (Table II).

Low static whey powder prices result from large constant supplies of unutilized whey solids hanging over the market. Whey utilization has been increasing, but whey supplies have been increasing even faster, causing an increase in unutilized whey solids--834 million pounds in 1975 compared with 770 million pounds in 1970 (Table III).

The economic impact of environmental controls will also substantially affect the whey industry. A recent EPA governmental study projected 12 percent closures of dairy plants due solely to environmental controls, in the half decade 1972-77--almost one-half of total plant closures in that period of time. Many of these involve inability to properly dispose of whey. The U.S. report also estimated consumer cost increases of 0.6 to 4.4 cents per pound of cheese just to cover the cost of environmental controls--many involving whey disposal[1].

---

[1] Economic Analysis of Proposed Effluent Guidelines for the Dairy Processing Industry. U.S. Environmental Protection Agency. November 1973.

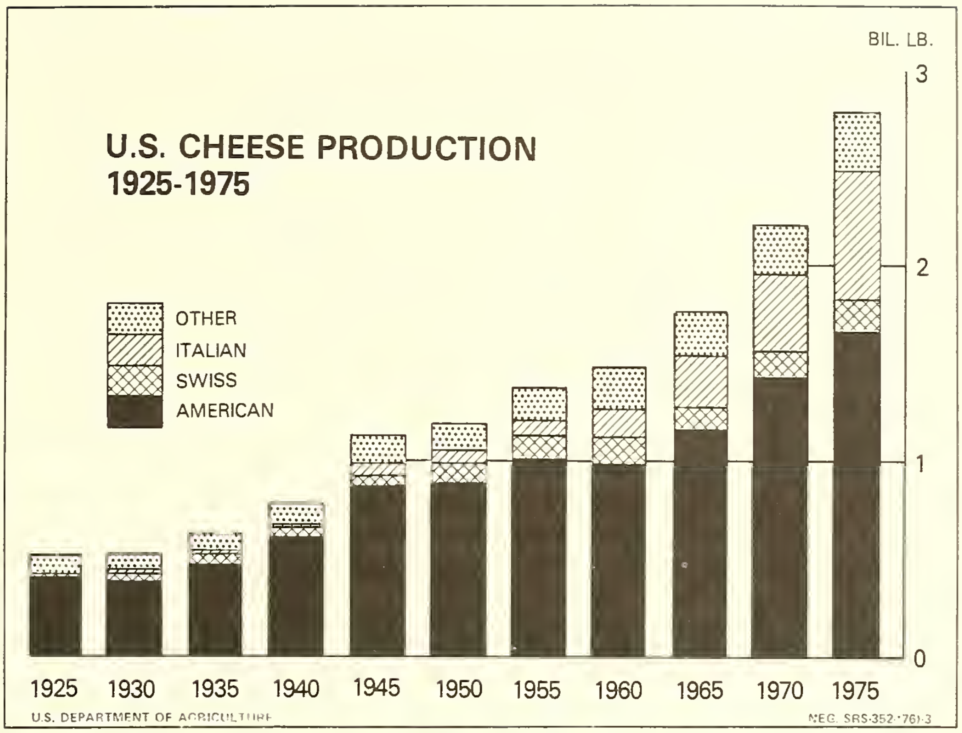


Figure 1

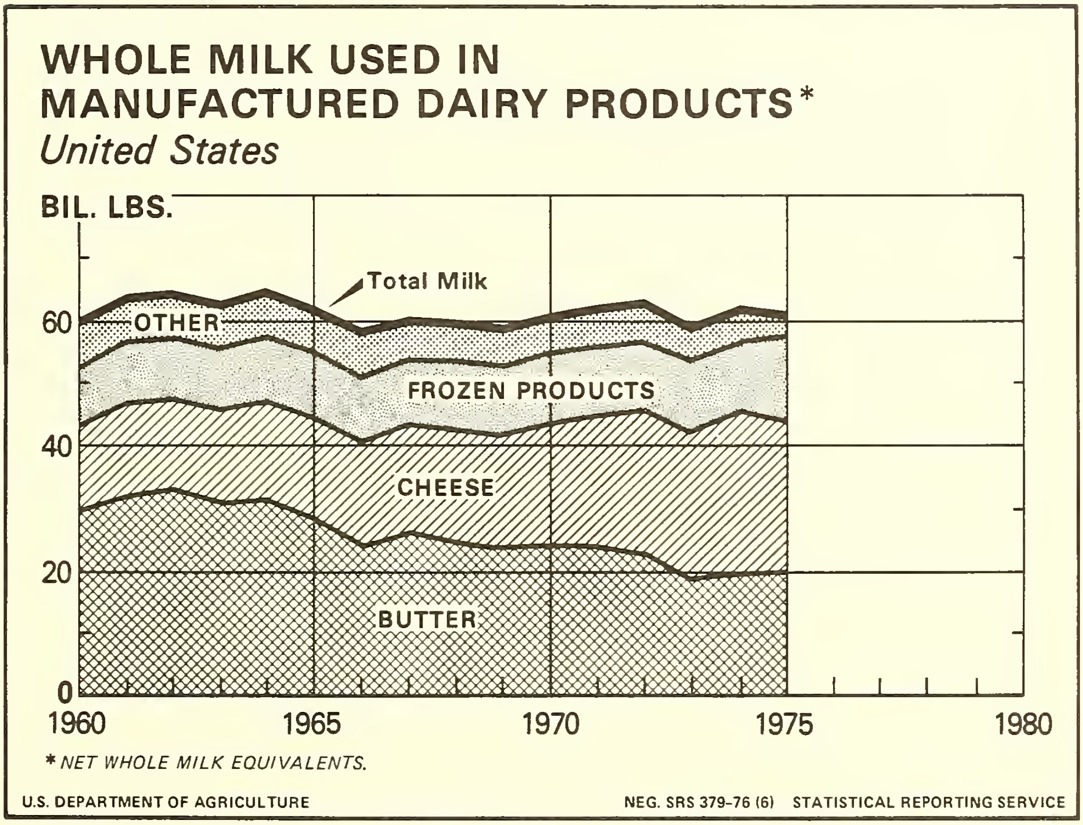


Figure 2

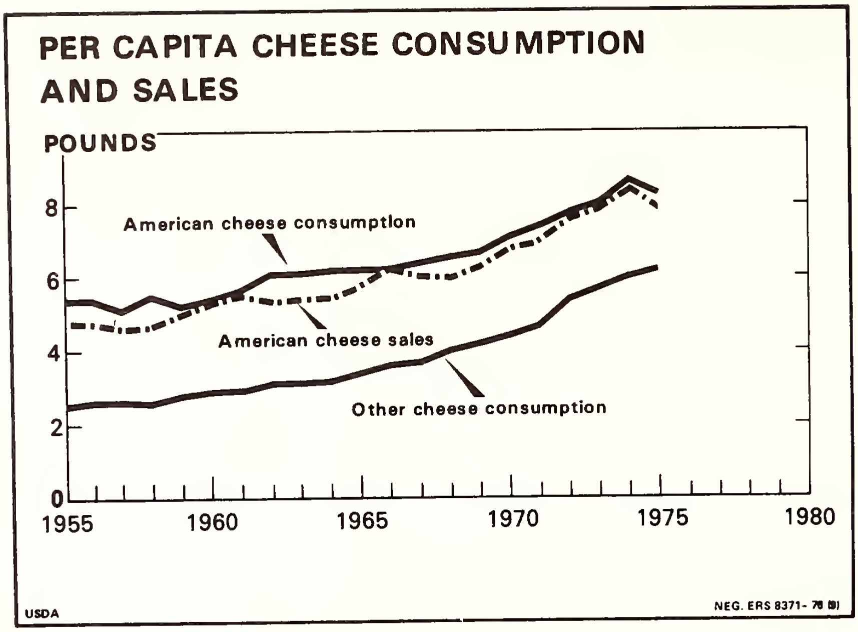


Figure 3

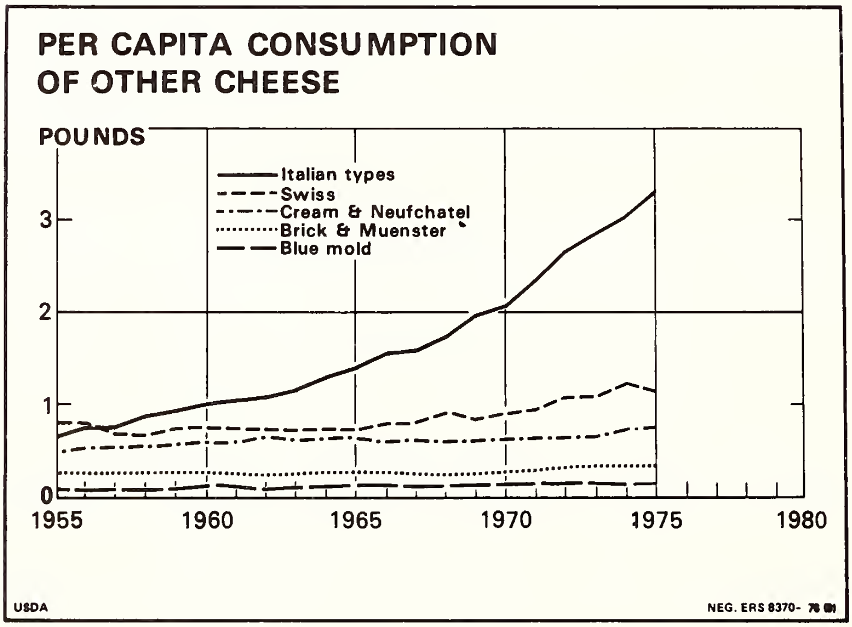


Figure 4

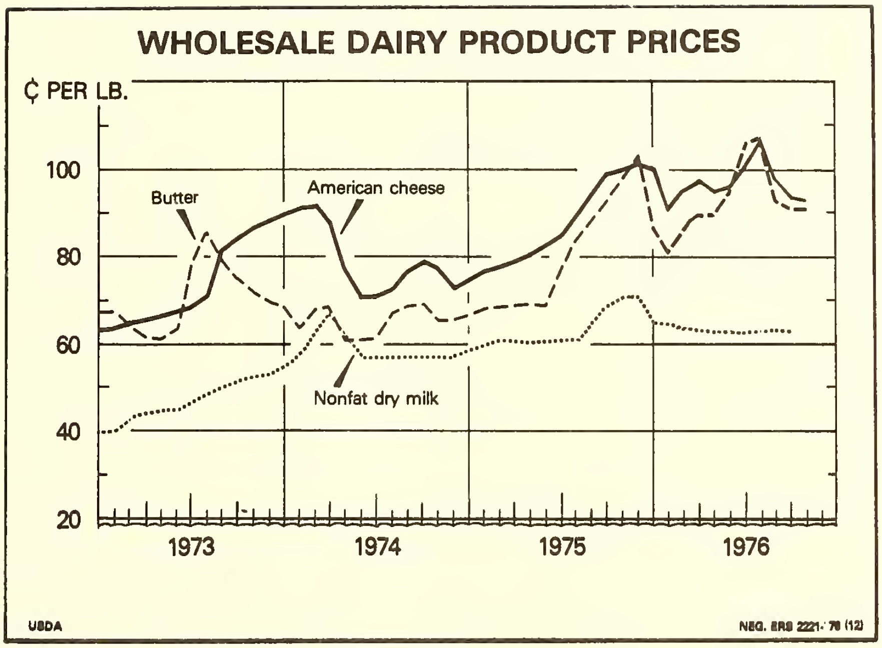

WHOLESALE DAIRY PRODUCT PRICES
¢ PER LB.
100
80
60
40
20
Butter
American cheese
Nonfat dry milk
1973
1974
1975
1976
USDA
NEG. ERS 2221-76 (12)

Figure 5

Table II.--U.S. wholesale prices of dry whey and nonfat dry milk, 1970-76

Year	Dry whey spray, feed[1]	Dry whey spray, food[1]	Nonfat dry milk, spray, food[2]	Dry whey for food as a % of nonfat dry milk
	Cents per pound			Percent
1970[3]	5.59	6.66	26.31	25.3
1971	4.84	6.55	30.74	21.3
1972	5.63	7.17	33.06	21.7
1973	7.65	9.49	46.38	20.5
1974	9.41	12.91	58.62	22.0
1975	6.02	7.55	63.32	11.9
1976[4]	6.25	7.50	64.50	11.6

[1] Central States production area.
[2] Manufacturers' average selling prices.
[3] June-December average for dry whey.
[4] Week of September 19, 1976.
Source: Dairy Situation, U.S. Department of Agriculture, Economic Research Service, DS-361, July 1976.

Table III.--U.S. whey solids, 1970-75

Item	1970	1971	1972	1973	1974	1975	Change 1970-75
	Million pounds						
Production	1,637	1,757	1,905	1,945	2,063	1,987	+350
Utilization	867	931	972	1,023	1,122	1,153	+286
Unutilized	770	826	933	922	941	834	+ 64

Source: Dairy Situation, U.S. Department of Agriculture, Economic Research Service, DS-361, July 1976.

The USDA estimates that current drying costs are 8 to 9 cents per pound for nonhygroscopic dry whey. These costs are approximately 1 cent per pound above present human grade whey powder prices and 2-1/4 cents per pound above prices for feed grade whey powder (into which human grade whey powder "backs," if it cannot be sold for food). Thus, whey drying operations are losing an average of 1 to 2-1/4 cents per pound of dry whey powder exclusive of liquid whey acquisition costs.

Only about 60 percent of the dry whey powder is now processed by cheese operations, leaving about 40 percent to be processed by specialized whey drying-marketing firms. With negative margins of 1 to 2-1/4 cents per pound on whey powder, these whey drying operations will no longer be able to pay for liquid whey, or even accept it "free of charge" if they are to maintain profitable operations.

Unless dry whey prices are increased or processing costs decreased, cheesemakers will increasingly have to pay specialized whey drying plants to accept liquid whey--if they accept it at all. Cheese will then have to carry the extra cost of drying whey, either as an adjunct of cheesemaking, or in payment to specialized whey drying operations. Whey disposal will increasingly become an added cost of making cheese rather than a breakeven or profit-making operation.

Tighter environmental controls will make whey "dumping" more difficult if not impossible. As a result, the whey industry will have to "dry" substantially increased volumes of whey and substantially increase sales, or mountains of unused whey solids will be accumulating.

Major countries processed less than one-fourth of their 103 billion pounds of liquid whey into dried whey powder in 1975. Only 17 percent of this whey powder was used for human food, leaving 83 percent for lower priced animal feed (excluding U.S. production).

Meanwhile, stocks of skim milk powder in western markets were nearly half of 1975 world production and nearly two years' average net exports. World-storage stocks of skim milk powder now exceed 4 billion pounds, and Eastern European Community (Common Market) countries have adopted a complicated program forcing the use of nonfat dry milk in animal feeds, if governmental financial aid in dairying is to be obtained. The United States has 42 percent of its annual production in USDA storage. In 1975, USDA price support purchases totaled 39 percent of total nonfat dry milk production.

World milk production is up one percent in 1976 to a new record and is expected to increase 50 billion pounds by 1980, almost one-half of our annual production.

These large volumes of whey and nonfat milk powder hanging over the world market have also depressed world prices of dry whey. For example, in 1975 dry whey prices were as low as 6.1 cents per pound in EEC countries.

Thus, the U.S. whey industry cannot expect much help on international markets. The world whey situation is as bad, if not worse, than the U.S. situation.

WHERE DO WE GO FROM HERE?

The stagnated whey situation results solely from increased supply, not decreased demand. Ironically, dry whey has been one of the major consumption bright spots in the entire dairy industry. For example, in the decade and one-half since 1960, per capita consumption of dry whey increased more than sevenfold to 2.3 pounds, in sharp contrast to a decrease in per capita consumption of about one-sixth in milk equivalent, one-fourth in fluid whole milk, one-half in nonfat dry milk, and two-thirds in dry whole milk (Table IV). Whey generated about $80 million on the wholesale market in 1975, up sharply by one-third from about $60 million five years ago.

Table IV.--Dairy products, per capita civilian consumption U.S., 1960

Year	Milk equivalent	Fluid whole milk	Nonfat dry milk	Dry whole milk	Dry whey
	Pounds				
1960	653	276	6.2	0.3	0.3
1965	620	264	5.6	0.3	0.6
1970	561	229	5.4	0.2	1.5
1975	547	196	3.3	0.1	2.3

Source: Dairy Situation, U.S. Department of Agriculture, Economic Research Service, DS-358, December 1975, and DS-362, September 1976.

Even though supply, not demand, caused the whey problem, paradoxically, the solution is demand, not supply. Why? Very simply because increased whey supply is "locked in" due to increased cheese production and environmental regulations restricting whey "dumping." Therefore, the sevenfold per capita dry whey sales increase in the past 15 years is not enough--substantially greater increases must be achieved if the whey problem is to be solved.

How then is the whey problem to be solved? Unfortunately, there is no one simple answer. Instead, a whole series of adjustments and experimentations will be necessary, including controversial changes in standards and regulations. Some promising possibilities to more fully capitalize on whey's potential include:

(a) Increased use for animal feed.
(b) Increased use as fertilizer.
(c) Increased use in ice cream.
(d) Increased use in meat products.
(e) Increased utilization of total whey constituents.
(f) Increased utilization of whey protein.
(g) Government price supports for dry whey.
(h) Higher government resale prices for supported dairy products.
(i) Tighter dairy import controls.
(j) Greater processing economies.

Segments of the dairy industry will support and others will oppose some of these recommendations. The major criticism probably will be that they result in some substitution of whey powder and nondairy products, for nonfat dry milk in human food and animal feed. However, like it or not, the age of consumerism--and imitation and filled products--has arrived, including imitation cheese. If the dairy industry doesn't capitalize on this situation, the sources outside the industry will, and likely substitute even more nondairy products. Thus, the whey industry must view a degree of intradairy industry competition and nondairy complementarity, as a fact of life--and an opportunity to increase financial strength--rather than a situation that must be avoided at all costs.

In my opinion, the above recommendations will benefit the total whey industry. Here's why:

Animal feed.--A major expansion outlet opportunity for dry whey is its increased utilization in animal feeds. This will necessitate improved storability, hence greater emphasis on nonhygroscopic whey powder. More emphasis will also have to be given to handling dry whey in bulk to reduce handling and transportation costs.

Research indicates dry whey is an excellent substitute for 40 percent or even more of the corn normally used in hog and poultry feed. Since dry whey has 12 to 13 percent protein and corn about 8 percent protein, it becomes profitable to substitute dry whey for corn, when the price of corn is within about 25 percent of the price of dry whey. With present prices of animal feed dry whey at about 6.25 cents per pound, substitution of dry whey for corn when corn reaches $2.63 per bushel therefore becomes profitable. In late September 1976 cost of ground corn to Midwest farmers is $2.85 per bushel (Chicago no. 2 yellow corn price plus 15 cents per bushel for grinding). In early 1976, the cost was $3.07 per bushel. Therefore, the substitution of dry whey for corn in hog and poultry feed is, and has been, highly profitable. "Future" prices indicate a cost to farmers of about $3.00 per bushel for ground corn in October 1977. Therefore, the substitution of dry whey for corn should continue to be profitable.

The growing world demand for meat and other animal products will increase feed grain demand, as exemplified by our mammoth grain and feed sales to Europe, Russia, China, and other countries--totaling $11.9 billion in fiscal year 1976. Grain export embargoes were imposed by the President several times in recent years and have been a major topic in the 1976 Presidential campaign, with both candidates promising not to reimpose embargoes except in national emergencies. Domestic utilization of the 834 million pounds of unutilized U.S. whey solids in feed would make consideration, let alone enactment, of grain export embargoes less necessary.

Research also indicates milk replacers can contain up to approximately 60 percent whey powder in the dry matter and still retain digestibility. Therefore, milk replacers containing mixtures of dry whey (12 percent protein), nonfat dry milk (36 percent protein), and soy flour (50 percent protein) or soy protein concentrate (70 percent protein) affort a golden opportunity for dry whey utilization. Combining these in a mixture containing 13 percent soy protein concentrate (34 cents per pound), 50 percent whey powder (6.25 cents per pound), and 12 percent nonfat dry milk solids (63 cents per pound), results in an excellent and competitive milk replacer for dairy calves, currently selling for about 31 cents a pound. It also affords an enlarged market for whey powder. Use of soy flour (18 cents per pound) in place of soy protein concentrate (34 cents per pound) results in an even lower-priced milk replacer, selling for about 27 cents per pound, but with lesser digestibility.

Soy flour and soy protein concentrate mixed with dry whey and nonfat dry milk could also be used as milk replacers in feeding veal calves and hogs and beef calves, during at least a portion of the feeding cycle, as the public becomes accustomed to the slightly pinker tinge in the meat from the soy product. This could also expand the market for dry whey.

Resisting combining dry whey with vegetable solids on the premise this reduces the market for nonfat dry milk will only increase vegetable competition, not increase nonfat dry milk sales, because vegetable solids prices are far less than nonfat dry milk solids prices. Hence, it is to the advantage of the whey--and dairy industry to increase, not decrease emphasis on these whey-vegetable solids animal feeds.

Fertilizer.--The nutrients in one acre-inch of liquid whey (about 110 tons) would cost approximately $150 to $175 if purchased as commercial fertilizer. Liquid whey used as fertilizer would, therefore, be worth about 7 cents per hundredweight to farmers--a very handsome return, since average drying costs are as high or higher than average dry whey prices. Dairies giving farmers liquid whey free of charge for use as fertilizer could gain in four ways: (1) by not losing money on drying operations as many are now doing, (2) by helping farmers financially, thereby improving good will, (3) by solving whey disposal problems, and (4) aiding society by returning whey nutrients to the soil.

One acre-inch of liquid whey per acre provides more than enough nutrients for the entire year, although applications of up to 8 acre-inches have proved successful on cornland--resulting in corn yields of up to 178 bushels per acre. Liquid whey for fertilizer works best on cornland and grassland, less well on alfalfaland, and should not be used on oatsland, since it causes oats to grow too rank, thereby increasing the danger of lodging. Whey helps prevent erosion by increasing the waterholding ability of soil. Whey also improved soil structure, thereby making soil easier to work, and is an excellent source of moisture, since 100 pounds of whey contains about 93 pounds of water. Land that is not wet or frozen is an excellent outlet for unutilized whey solids--some 42 percent of total whey solids in 1975. Application of whey on land is profitable for dairies and farmers alike.

Ice cream.--Another major expansion outlet opportunity for dry whey is its increased utilization in ice cream. The proposed frozen dessert standard of identity currently being considered by the Food and Drug Administration requires in ice cream a minimum "milk-derived" protein content of 2.7 percent from any milk-derived ingredients. This has caused a storm in the dairy industry, since it would permit substitution of casein products, for milk solids nonfat in ice cream. However, the proposed regulation could be a blessing in disguise for the whey industry, since it removes the 25 percent whey solids weight limitation in the solids nonfat portion of ice cream, resulting in no legal limitation on the proportion of whey protein in the 2.7 percent minimum protein content. The proposal would also permit combining dry whey and sodium caseinate in reaching the 2.7 percent minimum protein content in ice cream.

At present, sodium caseinate cannot be used to meet the 20 percent solids nonfat requirement in ice cream. Permitting the combination of sodium caseinate (at 18 cents per pound equivalent) with dry whey (at 7.5 cents per pound) makes possible attainment of the minimum 2.7 percent protein content at savings estimated by some in the industry of 1 to 10 cents per gallon of ice cream, compared with present costs, and without excess lactose which could result from the use of only dry whey. Therefore, this product combination could expand outlets for dry whey. Denial of this product combination could encourage mellorine, because it is cheaper than regular ice cream. Thus, supporting the proposed Standard of Identity, and capitalizing on it after it is promulgated, could be to the advantage of the whey industry.

Meat products.--The USDA Animal and Plant Health Inspection Service recently proposed to FDA that sodium caseinate and modified whey be permitted as binders in certain sausages and bockwurst, and as thickeners in other meat products. This regulation revision could be a boon to the whey industry and enable whey to compete more effectively with vegetable extenders in meats. At present, dry whey can be used only in nonspecific meat loaves, such as luncheon meats, but cannot be used in sausages and weiners. The new regulation, if promulgated, could result in substantially increased use of dry whey in the meat industry, and therefore affords another sales opportunity for the whey industry.

Increased utilization of total whey constituents.--Separation of the protein fraction of whey from the lactose-mineral fraction can be profitable. However, the U.S. current low price of 10 to 15-1/2 cents per pound for edible lactose and 15 to 22 cents per pound for refined lactose, world futures raw sugar prices for all of 1977 of under 10 cents per pound, a nine-tenths drop in world raw sugar prices in the past two years to 7.45 cents per pound, and a domestic sugar situation so desperate that the President recently tripled sugar import duties to 1.875 cents per pound put a lot of pressure on protein, when whey is fractionated. Complete utilization of whey constituents in an expanded array of foods and products can be a major solution to the whey problem.

It is true that whey is already used in a wide variety of bakery, dairy, meat, soup, candy, snack foods, baby food, soft drink, and pharmaceutical products. However, the world needs all the food nutrients it can get, and dry whey with approximately 12 percent protein, 73 percent lactose, and 9 percent minerals is an excellent source of nutrients. In this food-short world, it makes no sense for the United States to utilize less than 60 percent of our whey solids, and for major world countries to utilize less than one-fourth of their whey solids. Developing new food uses and markets for dry whey would not only help alleviate world food problems, thereby improving national security, but also provide expanded outlets for whey constituents.

Several international food conferences were recently held, including one in Rome, Italy, where strong support for a food reserve program is developing. What could make more sense from both an economic and humanitarian standpoint than to include unutilized dry whey in a "food reserve" reservoir? Why waste whey nutrients when the world is worried about food reserves? The whey industry is in the unique position of having extra food available, when the world is desperately looking for food. Unutilized whey solids represent a golden opportunity--not a problem--if you are willing to capitalize on it.

One unusually promising whey product for international use, particularly for overseas preschool feeding programs, appears to be a whey-soy drink mix containing whey solids (41 percent), soy flour (37 percent), soybean oil (12 percent), corn sugar (9 percent), and vitamin and mineral (1 percent). USDA estimated costs for this product averaged under 20 cents per pound in 1973-74[2]. This was less than one-half the cost of nonfat dry milk, in a period when dry whey prices were higher and nonfat dry milk prices were lower than they now are. Products of this type fit well in international food programs and, therefore, offer unusual opportunities for the whey industry.

The world is also seriously concerned about its rapidly diminishing natural resource base and eagerly looking about for new sources of supply--giving rise to zero population growth programs. Therefore, public and private research to expand the uses for unutilized whey solids in new products, particularly industrial raw materials, could also prove invaluable to the whey industry and society generally.

Marketing "grade A" dry whey would also help open up new markets that are not now available and should be given serious consideration by the whey industry.

Increased utilization of whey proteins.--Nutritionists tell us protein is one of two nutrients most often deficient in diets. For example, at present more than one-half the population of Bangladesh is suffering from protein deficiency. The world is turning away from starch diets to one based on animal protein, and in the process is attempting to increase the amount of animal protein available to consumers. This is a golden opportunity for the whey industry which has a high protein product.

The U.S. Government is also putting more emphasis on improving nutritional levels of young and old alike. Protein is therefore being stressed, and dry whey (with 12 percent) is an excellent source. At present about 22 percent of the protein in our diets comes from milk, illustrating the advantages whey has going for it.

Consumers are becoming more and more protein conscious, and protein has a glamorous ring to them. The whey industry with its high protein product can take advantage of this situation and expand markets and sales.

In this context, "whey protein powder," involving fractionating whey to result in a product with approximately three times as much protein as dry whey, offers substantial sales possibilities for the whey industry. This product has approximately 35 percent protein, 52 percent lactose, 6.5 percent ash, 3.5 percent fat, and 3 percent moisture. At present, much of this product is used in animal feeds. However, the proposed standard of identity for frozen dessert previously discussed could provide outlets for substantial volumes of this product in ice cream, since the 25 percent weight limitation on whey solids in the solid nonfat portion of ice cream would be removed, and the whey protein product could be combined with dry whey in meeting the 2.7 percent minimum "milk derived" protein content at a considerable savings. Use of whey protein powder in ice cream would also eliminate the need to add imported sodium caseinate, as would be the case if dry whey were used (because of less protein in dry whey), thereby increasing the use of domestic whey.

---

[2] Molde, H. H. Cost of whey-soy drink mix for human consumption. U.S. Department of Agriculture, Economic Research Service, Market Res. Rpt. 1021, May 1974.

Whey protein powder also could be excellent for fortifying fluid milk. At present, fortification of fluid milk with whey protein powder, although not specifically legal, is also not specifically illegal. The whey industry should work to get this legal question cleared up, since use of whey protein powder in fortifying fluid milk could result in considerably expanded sales for the product. Whey protein powder currently sells for about 40 cents per pound, compared with 63 cents per pound for nonfat dry milk solids. This powder has about the same protein content as nonfat dry milk, which is now used in fortification.

Food and Drug Administration standards requiring a minimum solids not fat content of 8.25 percent in whole, lowfat, and skim milk, in its final form for sale, shipped in interstate commerce, and requiring that fluid milk products contain 10 percent solids nonfat to be labeled "protein fortified," went into effect December 31, 1974. In the past there were no Federal standards for minimum solids nonfat content of fluid milk, or solids nonfat content required in fluid milk, to use the term "protein fortified." These new standards provide another sales expansion possibility for whey protein powder.

Dairy industry leaders are working to increase minimum solids not fat content even higher to at least 8.5 percent in whole milk, 9 percent in skim milk, and 10 percent in 2 percent milk. If achieved, this higher solids nonfat content would further expand sales potentials for whey protein powder, if legalization of its use in fortifying fluid milk were accomplished--a program for the whey industry to work on.

"Support" pricing for dry whey.--Whey was briefly "price supported" under the USDA price support program in 1951, but never since. The 800 million plus pounds of unutilized whey solids in 1975 give the whey industry a strong argument for reinstitution of price support on whey, particularly when tied in with governmental interest in Food Reserve, Food for Peace, and international food distribution programs. However, only dry whey that can be stored at least half a year is likely to be considered for price support. At present, much of the U.S. produced dry whey is hygroscopic and considerable quantities are also "roller dried." Both harden too rapidly in storage to be seriously considered for price support. The whey industry must emphasize spray-dried nonhygroscopic dry whey, if you wish to get price support for their product.

Higher resale prices for supported dairy products.--USDA current resale prices of supported dairy products are only 5 percent above Commodity Credit Corporation (CCC) purchase prices, as contrasted to the 15 percent markup which was in effect previously. Furthermore, the USDA has been accepting bids of over 58 cents per pound for standard grade nonfat dry milk, which was price-support purchased by CCC for 62.4 cents per pound. These USDA pricing decisions create additional problems for the whey industry, since larger quantities of government-purchased nonfat dry milk come back onto commercial markets, competing and interfering with the marketing of dry whey. If the whey industry could get the USDA to return to its former longterm resale price procedure for supported dairy products, this would be an advantage.

Import controls.--U.S. dairy imports were 6-1/2 times larger than exports in 1973, 5 times larger than exports in 1974, 3 times larger than exports in 1975, and 2 times as large as exports so far in 1976. It is in your economic interest to discourage further Presidential proclamations increasing dairy imports, since imported products, such as nonfat dry milk, compete directly with dry whey, while other imported dairy products reduce domestic production of these products. This forces more milk into USDA price-supported products, such as nonfat dry milk and cheese, thereby increasing competition for dry whey, and production of dry whey.

You must also be vigilant regarding export subsidies on dairy products shipped into this country, particularly by the European Economic Community. In 1975 the EEC removed subsidies of up to 48 cents on about 40 percent of the cheese normally exported to the United States (on Cheddar, colby, monterey, Emmenthaler, Gruyere, and low fat cheeses used for processing). This EEC action was taken under threat of countervailing duties by the United States. However, EEC subsidies still can be paid on Italian and other specialty cheese exports to the United States (60 percent of cheese exports), without threat of U.S. countervailing duties. This creates problems for the whey industry similar to those discussed above.

Finland also was subsidizing cheese exports at over one-half the U.S. domestic price, until threatened with countervailing duties.

The U.S. whey industry must guard against application of foreign export subsidies, and Presidential proclamations waiving import quotas, if it wishes to maintain strong domestic markets. The U.S. whey industry must remain vigilant on dairy import matters, until there is free international trade in dairy products to force a balance in supply and demand. The U.S. whey industry could compete very effectively in an international free trade situation, a policy position they could find to their advantage to support at the International Trade Conference currently being held in Geneva, Switzerland.

With present international trade policies in effect, the whey industry should consider a strong petition program for import quotas on lactose. At present, lactose is a nonquota product--one of very few. Last year 5.5 million pounds of lactose were imported, displacing domestic lactose from 150 million pounds of whey, and in effect creating an additional 150 million pounds of unutilized domestic whey which had to be disposed of in one way or another. With lactose in heavy domestic supply, with disastrously low lactose prices, and with strict environmental controls on disposition of unutilized whey, the whey industry has a strong basis for requesting import quotas on lactose.

Processing economies.--USDA estimates indicate that present drying costs are 8 to 9 cents per pound of human grade nonhygroscopic dry whey[3]. This is higher than dry whey prices in most U.S. markets. Therefore, a considerable premium exists on reducing whey drying costs. To compound the problem, many cheese operations are being forced to set up their own whey drying plants, since their whey outlets no longer have capacity or markets for the additional whey. Minimum whey drying costs are also critical to these cheese operations.

Research indicates that whey spray-drying costs are approximately one-half lower per unit in plants with a capacity of one million pounds of liquid whey a day operating at capacity than in plants of similar size operating at one-third capacity. Unit costs in full-capacity plants are one-fourth lower than in plants operating at one-half capacity. Similarly plants with a capacity of one million pounds of whey a day operating at capacity have 18 percent lower unit drying costs than plants with a capacity of 500,000 pounds a day, also operating at capacity[4]. Thus, size of plant and utilization of capacity are crucial factors in whey drying.

Research also indicates that concentrating whey and hauling the concentrate to a central drying plant reduces transportation costs by 84 percent as compared to hauling liquid whey[4]. Since transportation costs continue to increase with energy problems, condensing, if not drying, whey close to the cheesemaking operation is critical.

Summary.--While it may appear that current whey "surpluses" are a serious problem, in reality the current situation reflects a gigantic opportunity for the whey industry. This food-short world is desperately looking for new food supplies, and the whey industry has the product! You can capitalize on your opportunity if you accept and act on recommendations such as those I have made.

QUESTION: Would Dr. Graf expand a little more on the general trend in sugar prices?

DR. GRAF: The present wholesale price of sugar is running under ten cents a pound and the future price in sugar for next year is also something under ten cents a pound. As you recall, a couple of weeks ago, the President did triple the import tariffs on imported sugar, trying to buoy up the sugar market.

Well, you know what happened, oh, about a year and a half, two years ago, a very big shortage on sugar, and this supported lactose in whey, which expanded the market temporarily. People were talking about raising more sugar beets in Wisconsin, things like that, capitalize on this high sugar market.

---

[3] Torgerson, R. E. FCS, USDA, Letter to Author, 30 September, 1976.

[4] Groves, F. W. and T. F. Graf. An Economic Analysis of Whey Utilization and Disposal in Wisconsin, Agr. Econ. Bulletin 44, University of Wisconsin, Madison, July 1965.

QUESTION: What are your projections for the per capita consumption of meat and cheese in the near future?

DR. GRAF: One of the problems the dairy industry is going to have, at least in the next six months or perhaps longer, is a low beef price and a fairly low pork price. There isn't substitutability between dairy products and meat products. This is going to mean that we aren't going to be able to capitalize on fairly high meat prices during the period, people tend to eat more cheese and dairy products, at least for the next six months and perhaps the next year.

I'm not too sure these very substantial increases in per capita consumption of cheese that I showed on the screen a few minutes ago are going to be continued. The imitation cheeses coming along are not going to take over the market, but they are certainly going to be some competition. You've had this 50 percent increase per capita consumption of American cheese in the last decade, you have about 300 percent increase in per capita consumption of Italian cheese in the last decade, and of course, you reach a point where it's going to be harder to maintain those increases. That doesn't mean they are going to decrease, drop off drastically like butter, cream, and fluid whole milk did, but I think it is going to be somewhat difficult to try to maintain these increases.

In terms of what that means to the whey industry, I don't think you are going to have to have a big decrease in the volume of milk going into cheese, but I don't think you're going to have this continued increase, or at least as big an increase as you've had in the past. So I think in terms of whey, you've got a volume of whey now you are going to have to worry about getting rid of, but I'm not too sure it's going to expand as rapidly as in the past.

QUESTION: Mr. Chairman, I am not an agricultural economist and this is quite obvious for the moment, but I understood you to say that whey is facing great competition from nonfat dried milk. Now, with nonfat dried milk having a price of 60 cents per pound and dried whey in the order of six cents a pound, I would have thought it was the other way around, but indeed we are nearing that in Europe.

DR. GRAF: The question is whether whey is facing competition from nonfat dried milk, or is nonfat dried milk facing competition from whey? The gentleman says you would think it would be more a matter of nonfat dried milk facing competition from whey.

First of all, the U.S. Government is buying about 40 percent of all the nonfat dried milk produced. The USDA has about a half a year's supply of nonfat dried milk in storage, equal to about two years of exports of nonfat dried milk. With that quantity of nonfat dried milk available, the USDA is already forcing the feeding program or forcing them to use their nonfat dried milk in animal feeds in order to get continued support under the various government programs.

The U.S., as I indicated, is changing its policy. Recently, instead of charging 15 percent over the support prices selling it back to the trade, they are selling it back to the trade for five percent over the support price, and in the case of standard skim, they are actually selling it for less than the support price, 58 cents where the support is 62.4 cents a pound.

So I think the gentleman has a point. You would think with whey at six cents and skim milk at 62, it would be primarily a matter of whey being competitive with nonfat dried milk, and with all the nonfat dried milk around and a lot of it in government storage, this stuff is taking over the market, and as I repeat again, it's also creating a problem for dry whey, so I think it's probably competition.

QUESTION: With that much dry milk around, why doesn't it come down instead of being up around 63 a pound?

DR. GRAF: Well, because the support price is 62.4, but that's a good point.

On April 1, in this country, we raised the support price of milk from $7.71 a hundred weight up to $8.13 a hundred weight; that's 42 cents a hundred weight on milk. We raised butter six and a half cents a pound, we raised cheese five and a half cents a pound, and we cut the skim powder support at exactly the same level, 62.4. So the entire increase in the support price of milk in this country was put on butter and on cheese.

On October 1, just a week or two ago, there was a further increase in the support price on milk from 8.13 a hundred weight up to 8.26 a hundred weight. How was this accomplished that increase of 13 cents on milk? Again, by raising the support price of butter five cents a pound up to 92-3/4, by raising cheese supports by two cents a pound up to 92-1/2 cents for cheddar cheese, and no increase in the support price of skim milk powder.

So you may think 62.4 is too high, but when you've got a support for them, you have to support the price of milk anywhere from 75 to 90 percent of parity, and as the cost keeps going up, you have to keep raising those support prices. So for the last two years at least, they have put the entire burden on butter and cheese. This is clearly a problem.

In answer to your question, the reason it hasn't come is because the support price has been at 62.4, and the support price has been there because under the current law, they have to support at 75 to 90 percent of parity. In order to do that they have to dispose of the product. So they are pretty well locked in at 62.4 cents.

QUESTION: Purely economically speaking, not practically, isn't the support problem both here and in Europe a basic problem if you have a free market, your supply and demand going to balance and all make more money?

DR GRAF: Well, I think the question was, isn't the support program one of the main reasons for I guess the problem in the whey industry or in the dairy industry itself? I suppose you could argue that if you are thinking solely in terms of the whey industry selling whey powder or whey solids or cheese industry selling cheese or the butter industry selling butter. Actually the problem has not been as great in butter and cheese. As a matter of fact, two weeks ago the commercial cheese price was a bit above the support and the butter price somewhat above the support level. They have come down in the last month or two where they are pretty close to support level, and there weren't very many purchases by the government of cheese or butter in the past year.

Now in nonfat dried milk, it's true, the government is buying 40 percent of the production, so without that support the skim milk price would be a lot lower than it is now.

In terms of the industry trying to sell a product, you could argue, let's do away with all these support programs and, you know, you would be better off. Of course you've got to balance that against the interest of the producers, and you talk to these producers or groups and they claim they are not covering their cost of production the way it is. I think that this is true. As a matter of fact, the USDA just concluded a study a month or two ago and found the cost of production of milk in the USA is considerably more than the price that farmers have been getting.

So if you eliminate all these support programs, o.k., maybe you are going to solve some problems in the industry. But you are going to create some problems for the farmers, and of course a lot of those would be forced out of business. So, you know, there's two different approaches to this thing.

ELECTROMEMBRANE TECHNOLOGY FOR WHEY PROCESSING

R. M. AHLGREN

Aqua-Chem, Inc.
Milwaukee, WI 53201

ELECTROMEMBRANE PROCESSES

Electromembrane processes have been applied in the whey processing industries for approximately 20 years. The primary application is the use of electrodialysis or transport depletion for the de-ashing of whey solutions. Specialty products derived from ash reduction of either whole or partly de-lactosed whey are important ingredients in many specialty foods and form the basis of sound business ventures for some whey processors.

The modification that occurs in electromembrane processing is the reduction of the ash content or the soluble ionized salts and constituents in whey. Because electromembrane technology uses membranes as the basic separation media, there is often confusion between what is accomplished by electromembrane processing as compared to what is accomplished by reverse osmosis or ultrafiltration, the other two major membrane processes. Electrodialysis and other related electromembrane processes can reduce the ash and titratable acidity content of whey while leaving the protein and lactose content essentially unchanged. Reverse osmosis is a water removal or total solids concentration process; only water passes through the membrane while essentially all the protein, lactose, and ash are retained together on the feed side of the membrane. Ultrafiltration is a fractionating process in which the high molecular weight proteins are separated from the lower molecular weight ash and lactose which tend to pass through the membrane. Because none of the processes totally follow the ideal theoretical separation and there are many variations on the semantics or vocabulary of the trade, substantial overlapping of results and process confusion exist.

Electromembrane processes are, in fact, ion exchange techniques. They follow the basic fundamentals of ion exchange phenomena with a few significant variations. Some of these unique and significant aspects are:

- Only the ionized or electrically charged components of whey are influenced by the basic driving force of the process.

- A direct electric current is the driving force of the process--not chemicals or pressure.

- The feed fluid (whey) is retained in a specific stream or channel with membranes on either side. These membranes have the specific properties of allowing only ash components or charged nonprotein nitrogen compounds to pass through.

- Since ash is removed as long as whey is passed between the membranes and a DC current is applied, the process is both continuous in operation and has no dilution of the product by regeneration or auxiliary streams.

- Because of the continuity of the process and continual use of the ion exchange capability of the membrane, high concentration solutions can be easily treated.

Like virtually all processing techniques, electromembrane approaches have certain features or aspects that are limiting. One of these features is that the driving force of the process is the passage of an electric current. In solution, the presence of ionized or charged particles is necessary to maintain the practical flow of this electric current. Thus, it is not possible to use electromembrane technology to completely de-ash or deacidify whey. To design the removal of specific ash constituents into electromembrane processes is not as easy as it is into conventional ion exchange approaches. Nevertheless, the operating efficiency and the avoidance of auxiliary chemicals and difficult wast problems make electromembrane technology very attractive for whey processing.

The equipment used to carry out electrodialysis and electromembrane processing follows definite mechanical patterns. In contrast to the variety of different geometries that can be used in other membrane technology, electromembrane equipment all utilize flat sheet membranes. These membranes come in three distinct types: (1) Cation permeable (porous to sodium, potassium, or calcium); (2) anion permeable (porous to chloride, phosphate, or lactate); and (3) nonselective (porous to all ions but not protein or lactose). The membranes are held apart by separators or cells through which are passed the whey solution to be de-ashed, the brine solution picking up the ash, or other auxiliary fluids contributing to the total ion exchange process. The fluid cells and selective membranes are held together by end plates which make up the total stack assembly. Within these end plates are housed the electrodes (anode and cathode) that serve as the electrical poles or points of introduction of the DC current.

The total stack assembly which functions as the basic ash removal device is supported by auxiliary process equipment. This auxiliary equipment typically takes the form of recirculating pumps, typical process instrumentation, DC electric current power supply, and tanks or systems for the electrode rinse and brine streams. As in virtually all whey processes, auxiliary CIP equipment for daily cleaning and sanitizing is also required.

PRINCIPAL PROCESSING APPROACHES

Electromembrane processes as applied to cheese whey can be divided into two principal processing approaches and several newly developed variations on the fundamental approach. The basic processes, which are presently commercially applied are referred to as electrodialysis or transport depletion. These processes can be used on either sweet or acid whey at the normal concentration and conditions as they are collected from the cheese vat or they can be applied to concentrates of these wheys. The whey can be processed in either its naturally sweet or acid forms or it can be treated as a neutralized version of the acid type. In almost all cases, the ash portion of the whey and any existing titratable acidity are reduced in approximately equal percentage proportions. It is quite efficient and relatively easy from the technical standpoin to remove approximately 65 to 70 percent of these two constituents.

Either deashing or deacidifying the whey to a higher degree is desired. This can be done by electromembrane technology, but increasing difficulties are encountered. Under suitable electrical and chemical conditions, removal of up to approximately 90 percent of either the ash or acidity constituents from whey is possible. If removal beyond this 90 percent level is desired, resorting to classic ion exchange or other specialized techniques is usually necessary.

Electrodialysis

Typical or classical electrodialysis is shown in Figure 1. The solution treated here may be either standard sweet whey or acid whey from cottage cheese manufacturing as shown in the diagram. The two types of ion selective membranes are designated by "C" for cation permeable and "A" for anion permeable. Positively charged ash constituents, such as sodium, potassium, or calcium, are drawn toward the cathode (negative electrode) and pass through the cation membrane. However, these positively charged cations are repelled or retarded by the anion or negative ion permeable membrane. Conversely, the negatively

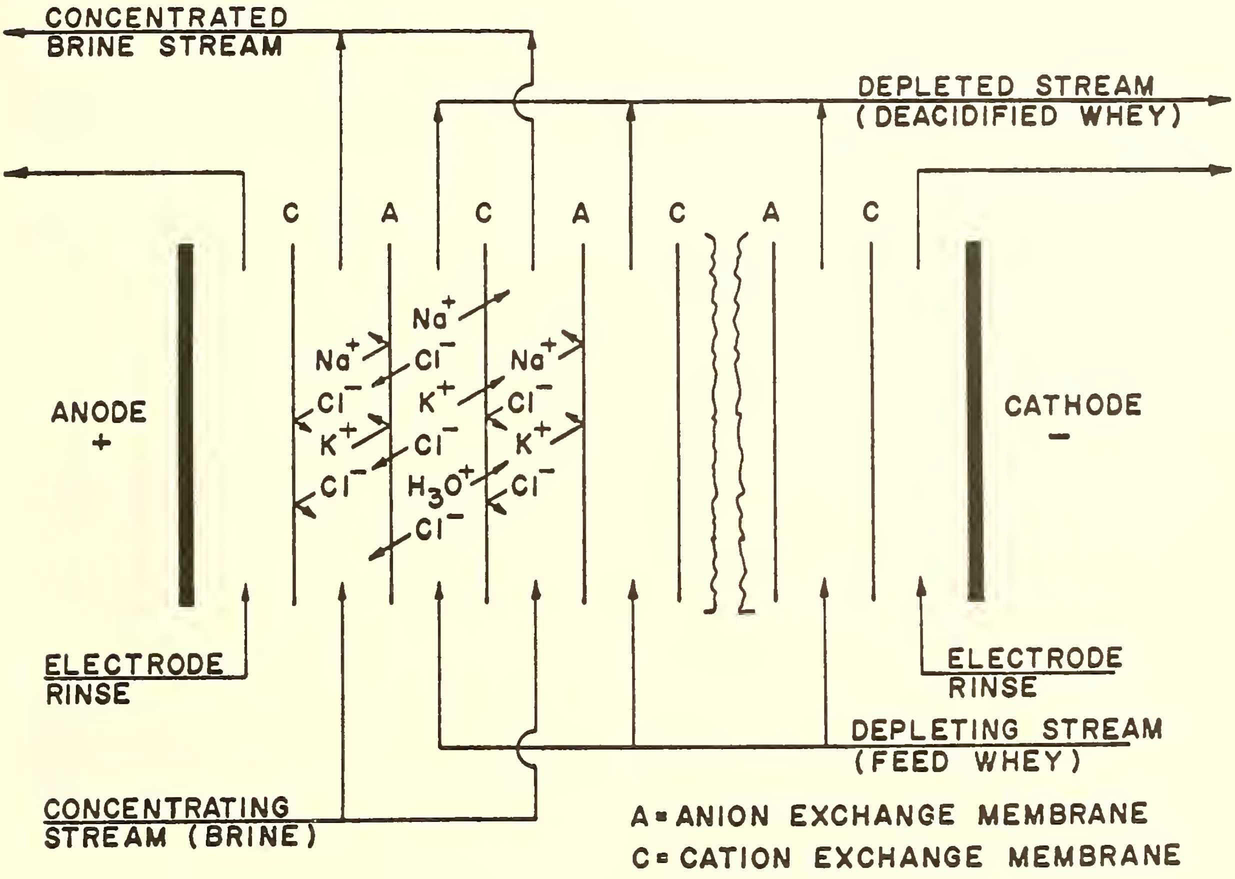

CONCENTRATED BRINE STREAM
DEPLETED STREAM (DEACIDIFIED WHEY)
C
A
C
A
C
A
C
ANODE +
CATHODE −
Na+
Cl−
K+
Cl−
Na+
Cl−
K+
Cl−
H3O+
Cl−
Na+
Cl−
K+
Cl−
ELECTRODE RINSE
ELECTRODE RINSE
DEPLETING STREAM (FEED WHEY)
CONCENTRATING STREAM (BRINE)
A = ANION EXCHANGE MEMBRANE
C = CATION EXCHANGE MEMBRANE

Figure 1.--Electrodialysis.

charged ash constituents, such as chloride, lactate, or phosphate, are drawn toward the anode (positive electrode) and are permitted to pass through the anion permeable membrane. They are retarded from passage through the cation permeable membrane by a mechanism similar to that which occurs to the cations at the anion membrane. Typical production rates for the process are high, and electrical energy consumption for the ash removal is acceptably low. When operated on sweet whey, it is not unusual to observe production rates of approximately 0.7 to 1.0 pounds of whey solids per hour per square foot of membrane at the 60 percent ash removal level. Operation on acid whey is less efficient and typically 0.2 to 0.3 pounds of acid whey can be similarly de-ashed and deacidified by one square foot of effective membrane in one hour's time. The electrical energy required for this operation is often less than one kilowatt hour per pound of whey solids de-ashed or deacidified.

Transport Depletion

Transport depletion (Figure 2) is similar to classic electrodialysis in operation and function except that a substitution is made in one of the membranes. In place of using an anion selective membrane, transport depletion uses a neutral or non-ion selective membrane. The basic capability of the process for de-ashing or deacidifying is not substantially different from typical electrodialysis. The special feature of the process is that the neutral or nonselective membrane is normally a less expensive component and is less subject to fouling than many of the anion exchange membranes. The overall effectiveness and economics of the process are similar to classic electrodialysis except that production rates are usually a little bit lower and the electric power consumption may be somewhat higher. The advantage of the process is that if the whey or fluid being processed contains potentially fouling anionic materials, there will be a lower membrane replacement cost.

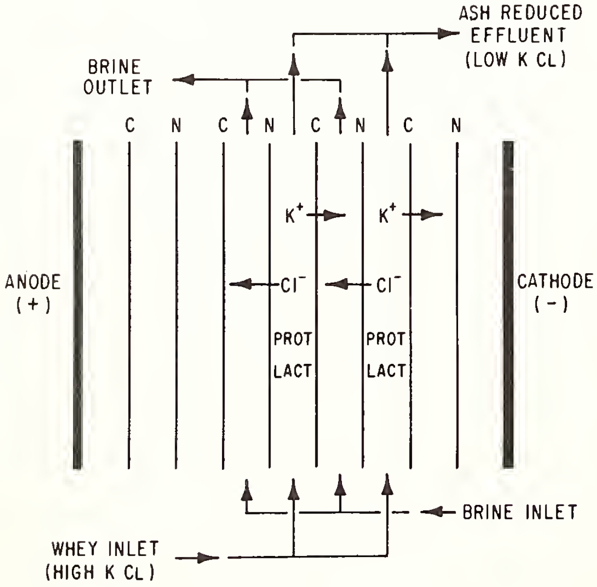


Figure 2.--Transport depletion.

This results from the twofold factor that the neutral membranes will normally last much longer than anion exchange membranes and will be less costly when such replacement is required. The general capabilities of transport depletion are similar to electrodialysis as previously stated. However, because of the absence of ion selectivity of one of the membranes, there is a somewhat more limited potential for higher percentage demineralization. The more extreme driving conditions and possibility for reverse diffusion of the ionized ash constituents make transport depletion less suitable at the high demineralization or deacidification levels.

Deacidification by Three Stream Electrodialysis

A new process for the deacidification of acid whey is depicted in Figure 3. This process uses a slight rearrangement of the ion selective membranes and also uses a third stream to contribute some of its desired constituents to the whey. As can be seen from the sketch, in this case whey is introduced to a cell or chamber which is bounded by anion exchange membranes on both sides. The result of this variation is that classical de-ashing or deacidification does not occur. Rather, an ion exchange in the whey is accomplished with a hydroxide (OH^-) anion being introduced into the acid whey while

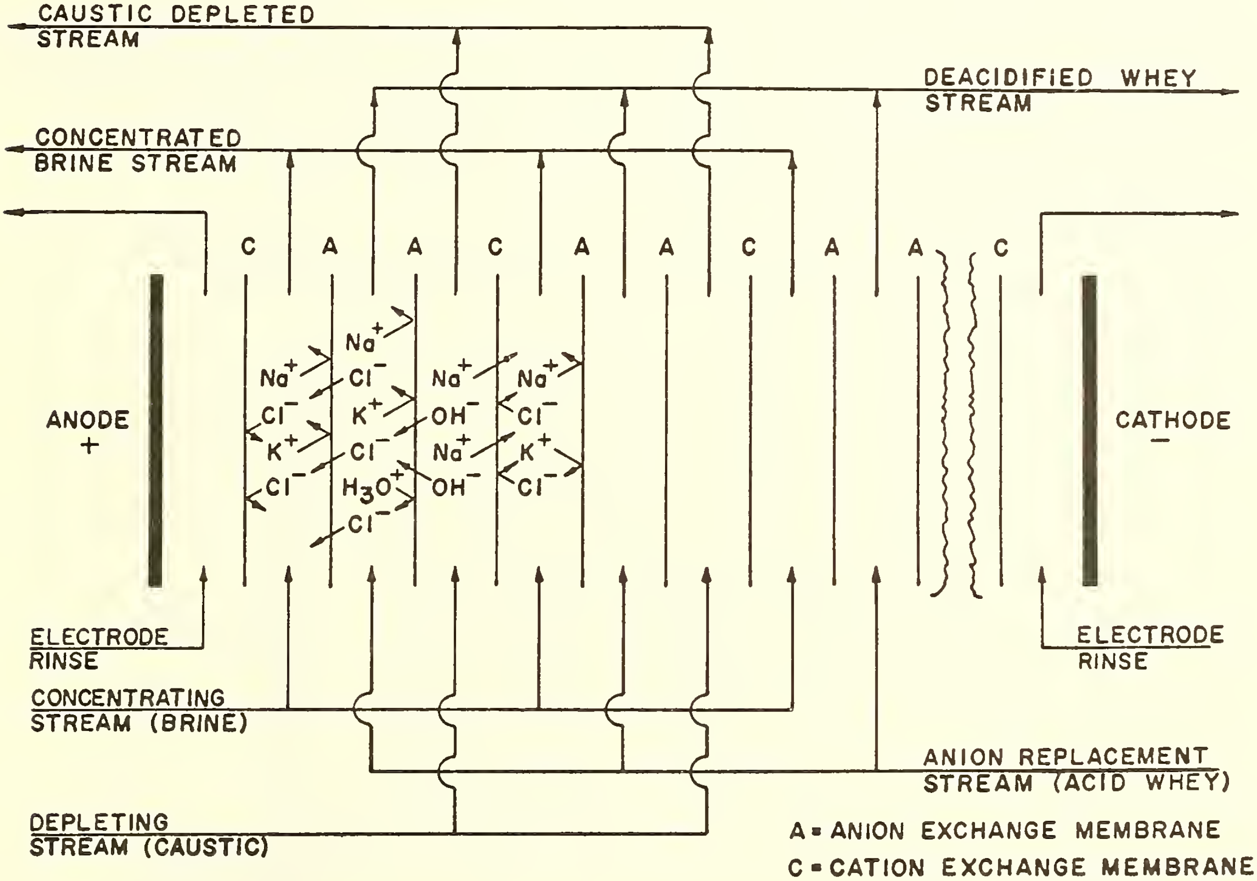

CAUSTIC DEPLETED STREAM
DEACIDIFIED WHEY STREAM
CONCENTRATED BRINE STREAM
C
A
A
C
A
A
C
A
A
C
ANODE +
CATHODE −
Na+
Cl−
K+
Cl−
Na+
Cl−
K+
Cl−
H3O+
Cl−
Na+
OH−
Na+
OH−
Na+
Cl−
K+
Cl−
ELECTRODE RINSE
ELECTRODE RINSE
CONCENTRATING STREAM (BRINE)
ANION REPLACEMENT STREAM (ACID WHEY)
DEPLETING STREAM (CAUSTIC)
A = ANION EXCHANGE MEMBRANE
C = CATION EXCHANGE MEMBRANE

Figure 3.--Three stream electrodialysis.

a lactate, chloride, or other anion is removed from the whey. The source of the hydroxyl ions is an auxiliary stream of dilute sodium hydroxide. The chloride or lactate anions removed from the whey are joined together with the sodium or other cation contributed by the caustic depleting or hydroxyl ion source stream.

The unique aspect of this process is that the titratable acidity of a stream is substantially reduced while the ash content is not. Where in classical electrodialysis or transport depletion the ash reduction and titratable acidity reduction follow approximately equal proportions, in this process the titratable acidity reduction can be almost any desired value while the ash reduction is usually less than 10 percent. The beneficial result of the process is that the productivity in terms of pounds of solids per hour per square foot of effective membrane is high, approaching that observed for electrodialysis of normal sweet whey. The electric power consumption is low because the absolute quantity of pounds or chemical equivalents of titratable acidity constituents removed is low. An additional cost is incurred for the caustic or hydroxyl ion contributing stream. However, overall this process is both efficient and economically attractive for the deacidification of cottage cheese whey. Some typical comparative figures for standard two stream electrodialysis and the three stream deacidification process on acid whey are shown in Figure 4.

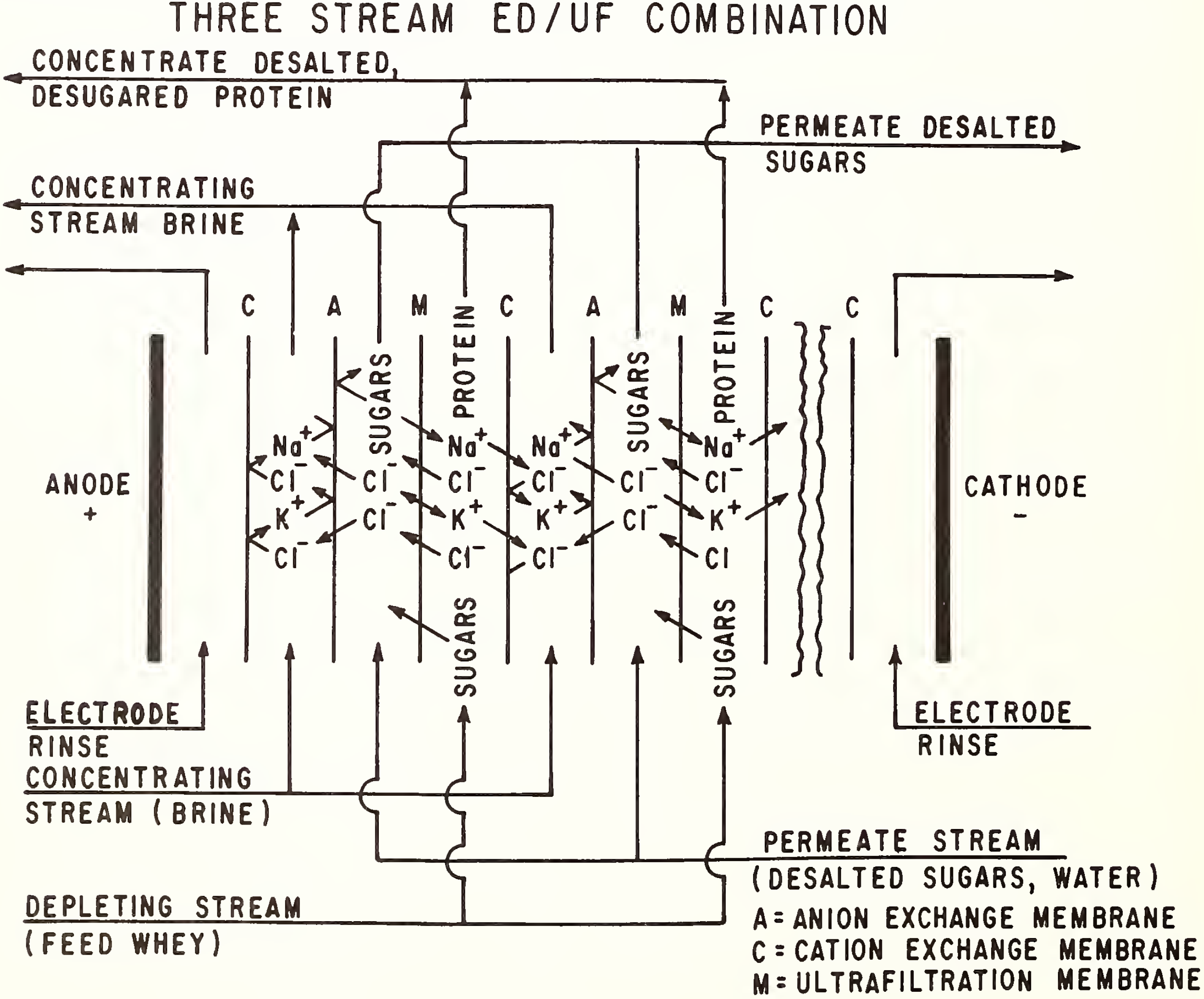

THREE STREAM ED/UF COMBINATION
CONCENTRATE DESALTED, DESUGARED PROTEIN
PERMEATE DESALTED SUGARS
CONCENTRATING STREAM BRINE
C A M C A M C C
SUGARS
PROTEIN
Na+
Cl−
K+
ANODE +
CATHODE −
ELECTRODE RINSE
CONCENTRATING STREAM (BRINE)
ELECTRODE RINSE
PERMEATE STREAM (DESALTED SUGARS, WATER)
DEPLETING STREAM (FEED WHEY)
A = ANION EXCHANGE MEMBRANE
C = CATION EXCHANGE MEMBRANE
M = ULTRAFILTRATION MEMBRANE

Figure 4.--Electrodialysis ultrafiltration combination.

TABLE I.--Economic evaluation for 50 percent de-ashing of 6 percent acid whey

Item	2 Stream ED	3 Stream ED
A. Liquid processed, lb. per day	1,000,000	1,000,000[1]
B. Pounds of solids processed, lb. per day	60,000	60,000[1]
C. % Titratable acidity removal	50%	50%
D. % Ash removal	50%	5%
E. Membrane area, ft^2	15,000	5,000
F. KwHr/lb. solids, processed	0.15	0.05
G. Lb.NaOH/lb. solids processed	None	0.035
H. Electrodialysis system cost $	1,125,000	375,000[2]
I. Capital recovery and interest $/day	1,020	340[3]
J. Membranes and maintenance $/day	204	68
K. Labor cost $/day	60	60[4]
L. Stack electrical power $/day	225	75[5]
M. Motor electrical power $/day	45	15[6]
N. NaOH $/day	0	273[7]
O. Miscellaneous costs	155	83[8]
P. Total daily cost $	1,709	914[9]
Q. Processed solids cost $/lb. solids	0.029	0.015[10]

[1] Based on 6 percent acid whey, 20 hr day, 220 operating days per year. Operating temperature, 105°F.

[2] This cost is for commercial equipment sanitary construction. It includes pumps, instruments, electrical power supply and complete electrodialysis stack and equipment. It does not include tanks or installation.

[3] Capital recovery is based on straight line depreciation over 10 years and 10 percent per year interest, both applied to Item H.

[4] Based on $5.00 per hour labor charge and 8 hours operator attention time plus 4 hours cleaning time for daily total of 12 hours.

[5] Based on power at $0.025 per KwHr and Items B and F.

[6] Used a value of one-fifth Item L.

[7] NaOH at $0.13 per pound and Items B and G.

[8] Used a value of 10 percent of Items I through N.

[9] Total of Items I through O.

[10] Item P divided by Item B.

Combination Electrodialysis and Ultrafiltration

Another new technique utilizing electromembrane processing concepts is referred to as combination electrodialysis/ultrafiltration. In this process, the usual electromembrane mechanism of de-ashing is operative as well as the ultrafiltration separation of high molecular weight proteins from lower molecular weight lactose or ash. The process utilizes three membranes as shown in Figure 4. These are (1) a cation (exchange selective) membrane that permits the passage of potassium, sodium, calcium, or other cations; (2) an anion selective membrane for the passage of chlorides, phosphates, lactates or other anions; and (3) an ultrafiltration membrane having the porosity necessary to retain proteins while permitting the passage of lactose or low molecular weight materials. The feed whey enters the stream having a cation membrane on one side and an ultrafiltration membrane on the other. Two transport mechanisms then occur simultaneously; ionized ash constituents are removed by the typical electrodialysis driving forces through the cation and ultrafiltration membranes, and high molecular weight proteins are retained in the feed stream while lactose and the anionic portion of the ash constituents pass through the ultrafiltration membrane. The result of this operation is that the feed whey stream is both protein-enriched and partly demineralized. The lactose solution that permeates through the ultrafiltration membrane enters the chamber or cell, which is bounded by an anion selective membrane and the backside of the ultrafiltration membrane. An additional separation mechanism occurs, then, in this stream. Since lactose is not an ionized constituent, it moves no further and is not affected by the electric current which promotes the continuing flow of the chloride or anion constituents through the anion exchange membrane into a typical brine or ash collecting stream.

The net result of the process is that whey is now fractionated into three distinct streams as opposed to the two streams that are generated by either electrodialysis or ultrafiltration if applied alone. The initial feed whey has the protein constituents retained while the lactose and ash have been diminished. The properties of this stream can resemble the high protein concentrations available through ultrafiltration while also exhibiting the lower ash levels which can be accomplished by electrodialysis. The lactose or permeate stream generated by the process is different from normal ultrafiltration in that a substantial portion of the ash has been removed. Whereas in normal ultrafiltration the permeate stream may contain anywhere from 10 to 15 percent ash on a dry-matter basis, this lactose stream can contain as little as only 1 or 2 percent ash on a dry-matter basis. The third or removed ash stream from the process is basically similar to that collected from normal electrodialysis. It consists of the cations, which were removed from the feed whey through the cation exchange membranes, and the anions, which were removed through both the ultrafiltration and anion exchange membranes in sequence.

The basic economics and productivity of the process are high and resemble the values that would be observed for either electrodialysis or ultrafiltration if applied as to separate distinct processes. An added advantage is observed with this process in that if the feed whey solution contains constituents that are potentially foulants to an anion selective membrane, they are, in fact, held away from that anion selective membrane. Since the anion membrane sees essentially protein-free ultrafiltration permeate, relatively little anion membrane fouling is observed.

SUMMARY

Electromembrane processes have a unique utility in the field of making protein-rich specialty products from cheese whey. The reductions in ash and acidity are both predictable and economical. Equipment can be built and operated under the best conditions of sanitation and product control. The sometimes difficult situation of disposal or processing of high ash, lactose solutions resulting from ultrafiltration operations alone can be improved by special approaches. The use of a combination electrodialysis/ultrafiltration process or the simple application of classical electrodialysis to ultrafiltration permeate permits substantial upgrading of this stream. The avoidance of some pollution problems associated with auxiliary chemicals from normal ion exchange operation are clearly avoided through the use of electromembrane technology. The costs of electrical power for these ash removal steps is substantially better than the comparable cost of chemicals for usual ion exchange techniques.

Deacidification of cottage cheese whey by modified three stream electrodialysis has interesting processing possibilities. Through the use of this technique low value acid whey, which has often posed a disposal problem, can be upgraded to a desirable byproduct and constituent in food formulations.

With the development of specialty approaches to electromembrane processing, much can be done in the fractionating, improving, and upgrading of whey-derived protein and specialty products.

QUESTION: I would like to ask Mr. Silverman if he is free to disclose what types of oils are being used in the plant put together in Germany and that are coming on stream, the one plant coming on stream in the United States.

MR. SILVERMAN: We have been using a variety of oils, oils that are naturally used for milling requirements, which are not only lard and tallow and vegetable oils, we have been using some soy oils, and I suppose eventually, although I'm not sure if they answer the entire problem, they will be using butter oils in their system. But we use a complete range, and as mentioned before, the oil really is not much of a difference, makes no differnece for what is used in the system.

QUESTION: I would just like to ask Mr. Ahlgren if he would like to comment on effluent problems associated with electrodialysis, electromembrane processing.

MR. AHLGREN: In addition to the inorganics that are in the brine or waste treatment of the electromembrane processing, you have various categories of constituent BOD.

With most of the ion selective membranes that we are using today, the BOD of that waste brine is--I would use the word relatively low as the general answer, that meaning anywhere from a few hundred up to perhaps a thousand or two parts per million BOD in the brine stream.

Now, if we use a process such as the cation neutral type of system, where one of the membranes is not an ion selective membrane, you do have higher primary sugar losses or higher BOD's in that waste brine stream.

This of course is also a function of the total solids concentration of which you operate. If you are operating on the six per cent whey, such as I indicated on the chart here, the BOD of those brine streams is typically, with selective membranes, only a couple of hundred parts per million, in some cases even less. We've got some 30 or 40 or 50 parts per million of BOD's.

If you are operating one plant, for example, operating about a 42 per cent delactosed molasses, the BOD of that brine stream is several thousand parts per million.

So it's a broad spectrum, broad answer, but these are the range of that magnitude.

QUESTION: What is ratio of brine to whey when you are running? Because we are interested in figures. You also have to consider what the volume is with these figures. Is it one to one or two to one? What is the volume of brine to volume of whey concentrate?

MR. AHLGREN: Again that's a fairly flexible situation. You can pick the quantity of brine, or that is, the brine concentration on several different bases. If you wish to more or less optimize the energy consumption, I would make the rather broad answer that probably the best brine concentration is in the order of equal to the same concentration of those ionized salts in the whey.

For example, in the delactosed molasses with total solids of about 42 percent, the ash or the salts, let's say, the ionized salts on a solution basis are about eight per cent. In other words, approximately 20 per cent of the solids are ash, or about eight per cent of the solution basis, so that the brine could be somewhere in that same strength.

It's obviously an advantage to carry the brine at a much higher concentration, you have much less of a waste problem. But then you are fighting what I would refer to as a back dialysis or back dilution problem, it takes a certain amount of electric power or current flow just to simply tread water, to keep the high concentration of salts in that brine stream from defusing back into the whey stream. So you can minimize the waste problem, but you lose a current efficiency.

You can go on the other side of the coin, we have done this, we have had some rather interesting results--I'm sure other electromembrane people have--to put whey in the product side, put essentially plain or fresh water in the brine side, and forget to turn the power on and just let the salts go across simply by straight dialysis. Here you have the other extreme with extremely low concentrations, but you minimize it.

By and large I would say the answer would be approximately equal concentrations of any percentage or productivity basis to that the whey is processed.

ADVANCES IN ULTRAFILTRATION PROCESSING TECHNOLOGY AS RELATED TO APPLICATIONS IN THE DAIRY INDUSTRY

B. R. BRESLAU

Romicon, Incorporated
Woburn, MA 01801

INTRODUCTION

The use of ultrafiltration in the dairy industry has grown dramatically over the past few years. This growth is largely due to the development of improved or "second generation" membranes,[1,2] membranes which can routinely cope with the exacting cleaning and sanitation requirements of the dairy industry. But it is also due to less heralded, but equally significant advances in processing technology which are having a pronounced impact on the performance of today's systems. These advances in processing technology are the subject of this paper.

DEFINITION OF TERMS

In the discussion that follows, a number of terms are used that have multiple meanings. Rather than risk confusion, their intended meanings are listed below.

The Degree of Concentration

The degree of concentration is a measure of the extent of concentration of the feed stream. It is usually expressed as a dimensionless number in terms of a concentration factor (CF) or a recovery (R). The concentration factor is based on the amount of concentrate produced and is defined as the ratio of the feed volume or feed flow rate to the concentrate volume or concentrate flow rate.

$$CF = \frac{\text{Feed Volume}}{\text{Concentrate Volume}} \qquad (1)$$

$$CF = \frac{\text{Feed Flow Rate}}{\text{Concentrate Flow Rate}} \qquad (1')$$

Thus, if a 1,000 gallon batch of whey was concentrated to 100 gallons, the concentration factor would be 1,000/100 = 10. In this case if the protein fractions of the whey were completely retained by the membrane, their concentration would have increased by a factor of 10, or 10X.

---

[1] Breslau, B. R., Agranat, E. A., Testa, A. J., Messinger, S., and Cross, R. A. 1975. Hollow fiber ultrafiltration. Chem. Eng. Prog. 71(12):74-80.

[2] Breslau, B. R., Kilcullen, B. M., and Cross, R. A. 1975. Hollow fiber ultrafiltration of cottage cheese whey, a performance study. Amer. Dairy Sci. Assoc., 70th Annual Meeting.

The recovery of the system on the other hand is based on the amount of permeate produced and is defined as the ratio of the permeate volume or permeate flow rate to the feed volume or feed flow rate.

$$R = \frac{\text{Permeate Volume}}{\text{Feed Volume}} \qquad (2)$$

$$R = \frac{\text{Permeate Flow Rate}}{\text{Feed Flow Rate}} \qquad (2')$$

Thus, following through with the example above, if a 1,000 gallon batch of whey was concentrated to 100 gallons, 900 gallons of permeate would be produced and the recovery of the system would be 900/1,000 = 0.90 or, if expressed as a percentage, 90.

Obviously the use of either the term concentration factor or recovery to describe the degree of concentration of a system is arbitrary and the terms can be related as follows:

$$CF = \frac{1}{1-R} \qquad (3)$$

A tabulation of concentration factor vs. recovery as described by equation 3 is presented in Table I for reference.

The Rejection Coefficient of the Membrane

The rejection coefficient of the membrane (σ) is a quantitative measure of the ability of the membrane to retain a given solute species[3]. It is defined by equation 4 where c_p and c are the concentrations of the solute in the permeate and concentrate streams, respectively.

$$\sigma = 1 - \frac{c_p}{c} \qquad (4)$$

If the solute were completely retained by the membrane, its concentration in the permeate stream would be zero ($c_p = 0$) and its rejection coefficient would be 1.000. At the other extreme, if the membrane did not retain the solute, and the solute readily passed through the membrane, its concentration in the permeate stream would equal its concentration in the retained stream ($c_p = c$) and its rejection coefficient would be 0.000. Membrane rejection coefficients therefore lie in the range of $0.000 \leq \sigma \leq 1.000$.

In the case of whey, a number of solute species are present and individual rejection coefficients should be obtained for each species. For example, the Romicon XM50 membrane, which is a 50,000 molecular weight cutoff membrane, has a rejection coefficient for protein (TCA precipitable protein) of 0.972

---

[3] Karger, B. L., Snyder, L. R., and Horvath, C. In An Introduction to Separation Science, 1973, Chapter 16, John Wiley and Sons.

TABLE I.--The relationship between concentration factor and permeate recovery[1]

Concentration factor	Permeate[2] recovery	Concentration factor	Permeate[2] recovery
1.00	0.000	6.00	0.833
1.50	.333	6.50	.846
2.00	.500	7.00	.857
2.50	.600	7.50	.867
3.00	.667	8.00	.875
3.50	.714	8.50	.882
4.00	.750	9.00	.889
4.50	.778	9.50	.995
5.00	.800	10.00	.900
5.50	.818	10.50	.905

[1] $CF = 1/(1-R)$.

[2] Often expressed as a percentage by multiplying by 100.0.

indicating good retention; its rejection of lactose on the other hand is only 0.089 indicating poor retention. The Romicon PM10 membrane, which is a much tighter membrane with a molecular weight cutoff of 10,000, has a protein rejection of 1.000, which is only 3 percent greater than that of the XM50 membrane, but its lactose rejection is 0.240 which is over 200 percent greater than that of the XM50. This illustrates an interesting point: the main differences in the rejection characteristics of the membranes used in whey processing today are in the rejection coefficients for the lower molecular weight species (lactose, ash, low molecular weight peptides, etc.), not protein. In almost all cases, the rejection coefficient for protein will exceed 0.950.

Solute Yield

The yield (Y) of a system with respect to a given solute is defined as the fraction of the solute retained in the concentrate stream compared to that which was present in the feed.

$$Y = \frac{\text{Solute retained in concentrate}}{\text{Solute present in feed}} \tag{5}$$

This term is perhaps the most misused term in membrane technology. Solute yield is often confused with the rejection coefficient of the membrane but it is actually quite different in that it is not a property of the membrane, but a function of how the membrane was used. Its functionality depends on the rejection coefficient of the membrane, the degree of concentration, and the mode of operation of the system.

$$Y = f\ (R, \sigma, \text{Mode of Operation}) \qquad (6)$$

Thus, to specify the yield of a system for a given species is impossible unless the mode of operation is specified (batch, continuous, single pass, recirculating, staged, etc.) as well as the degree of concentration required and the rejection coefficient for that species.

MODES OF OPERATION

The method of operating an ultrafiltration system is perhaps the single most important process variable affecting both system capacity and yield. In this section a comparison is offered between batch operation and continuous feed and bleed operation. The examples used in the comparison refer specifically to hollow fiber systems, but the conclusions that result are perfectly general and apply to all types of membrane systems. It is instructive to start with batch operation because this mode of operation serves as a standard of comparison for all other modes of operation and also provides the type of data needed to design continuous feed and bleed systems of any number of stages.

Batch Operation

In batch operation (Figure 1a) whey is supplied to the ultrafiltration system from a batch tank and is continuously recirculated through the hollow fiber cartridges. As the whey flows through the cartridges, the whey is progressively dewatered and returned to the batch tank. Since the production of permeate is continuous, the level in the batch tank gradually drops and the protein and solids content of the recirculating stream increases. This operation continues usually from 4 to 10 hours, until the protein or solids content of the concentrated whey meets the specifications of the desired end product.

The performance of a batch system is presented graphically in the flux (J) versus concentration factor (CF) graph of Figure 2. The flux or rate of permeate flow in gallons per square foot of membrane area per day (GSFD) is plotted as the ordinate while the logarithm of the concentration factor is plotted as the abscissa. As would be expected, the flux of the system, shown as a solid line, decreases gradually as the whey being recirculated becomes progressively more concentrated. In this example, which refers to a run in which a cheddar cheese whey was concentrated to the 35 percent protein level, an initial flux (J_o) of 27.9 GSFD was observed which gradually dropped to a final flux (J_f) of 17.9 GSFD.

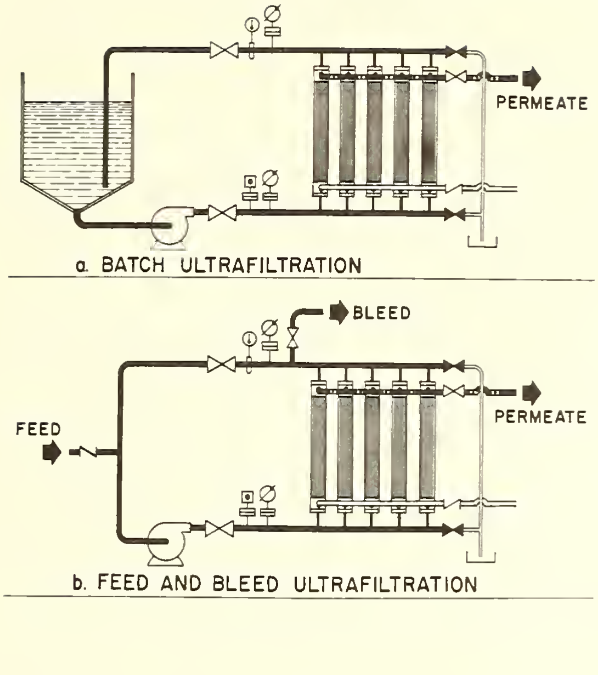


Figure 1.--Schematic representation of the batch and feed and bleed modes of operation.

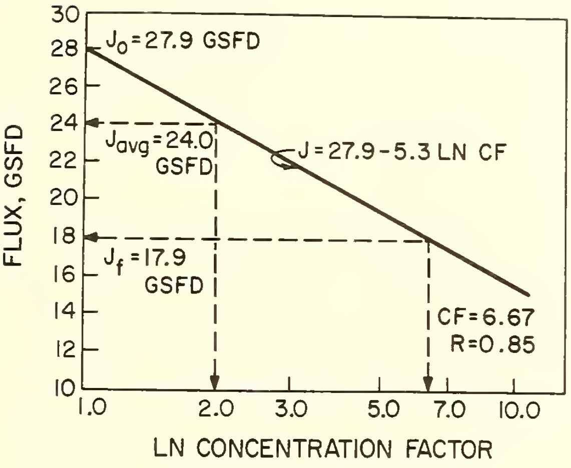


Figure 2.--Flux versus concentration factor profile for batch operation. This profile refers to a cheddar cheese whey which produces a whey protein concentrate of 35 percent protein (TKN) when ultrafiltered to a concentration factor of 6.7.

By rigorous mathematical analysis the average flux of this run could be shown to be 24.0 GSFD[4] but, for reference, a good approximation of the average flux could be obtained by equation 7.

$$J_{ave} \approx J_f + \frac{2}{3}(J_o - J_f) \qquad 7$$

which gives an average flux of 24.6 GSFD. This differs from the mathematically rigorous average flux by only 2.5 percent. Note that in batch operation the average flux is very definitely biased toward the high end.

Additional examples of the flux profiles obtained in batch ultrafiltration are shown in Figures 3 and 4. Figure 3 shows data that were obtained in two runs with cottage cheese whey at a pH of 4.6. The only difference between these runs was in the average transmembrane pressure which is defined as the average pressure across the membrane, from the process side to the permeate side[5]. Since hollow fiber systems usually operate at a constant cartridge inlet pressure of 25 psi, increasing the transmembrane pressure simply means increasing the cartridge outlet pressure, which has the effect of reducing the rate of recirculation of the process stream through the lumen of the fibers. Thus, the data of Figure 3 indicate that it is not necessary to operate at very high recirculation rates when processing cottage cheese whey. This conclusion is not universal as indicated by the flux profiles of Figure 4 which refer to four runs made with fortified skim milk[5]. In these runs, increasing fluxes were obtained by lowering the average transmembrane pressure, which has the effect of increasing the rate of recirculation of the process stream. Thus, these data indicate that high recirculation rates are needed to process fortified skim milk.

The examples given above show that the logarithmically decreasing flux trend postulated for batch systems is observed irrespective of the type of flow behavior that is required for optimum performance.

Continuous Feed and Bleed Operation

In continuous feed and bleed operation (Figure 1b) the batch tank is eliminated and a line is added to allow the recirculation loop to be closed. Whey is then fed to the system at a rate equal to the sum of bleed and permeate rates. For example, if the system was operated at a concentration factor of 10, and the feed rate was 10 gpm, then the bleed and permeate rates would be 1 and 9 gpm, respectively. In this mode of operation the rate of recirculation is very high in comparison with the feed rate so that perfect mixing within the loop can be assumed. The concentration of the recirculating stream, therefore, must be equal to the specified concentration of the bleed stream since the bleed stream is taken off of the recirculation loop. From a physical point of view this means that a feed and bleed system operates at the concentration

---

[4] Breslau, B. R. The mathematics of ultrafiltration. (Submitted for publication.)
[5] Kilcullen, B. L., and Breslau, B. R. 1976. Hollow fiber ultrafiltration of skim milk. Amer. Dairy Sci. Assoc. 71st Annual Meeting.

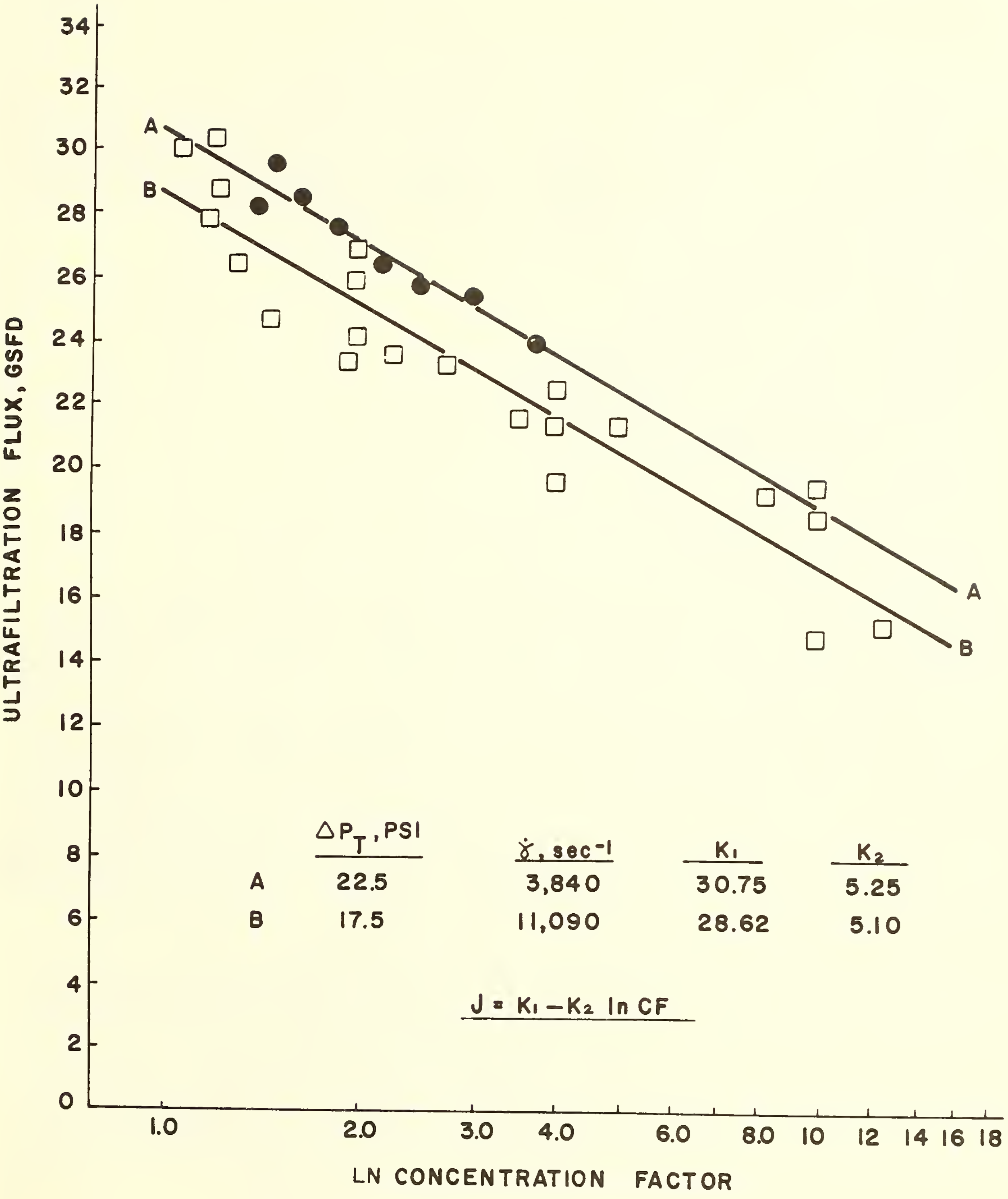


Figure 3.--The flux versus concentration factor profiles for the batch ultrafiltration of cottage cheese whey showing the effect of transmembrane pressure on flux.

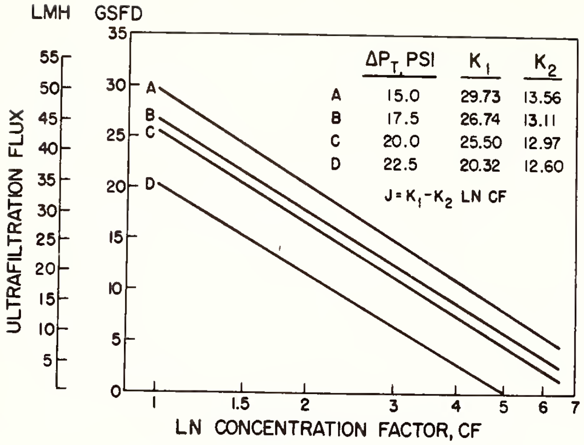


Figure 4.--The flux versus concentration factor profiles for the batch ultrafiltration of fortified skim milk showing the effect of transmembrane pressure on flux.

factor of the bleed stream. This is illustrated in Figure 5, which is the flux versus concentration factor profile obtained from batch studies applied to a single stage feed and bleed system. The flux profile is, of course, still valid. However, whereas the entire range of concentration factors are experienced in batch systems, only the final concentration factor is experienced in a single stage feed and bleed system. Thus, the single stage feed and bleed system of Figure 5 would operate continuously at a concentration factor of 6.67 and a flux of 17.9 GSFD which would compare directly to the 24.0 GSFD average flux obtained in batch operation for the same degree of concentration. This example thus illustrates another important point: in any ultrafiltration operation, the highest average flux for a given concentration range, all other things being held equal, will be obtained via batch operation. All other modes of operation must give a lower average flux.

To increase the average flux of a continuous feed and bleed system one simply has to add staging. In staging the overall concentrating function of the system is divided into steps with each stage carrying out one step. Thus, in a 3-stage system (Figure 6) the concentrate produced in the first stage would be passed on as feed to the second stage where it would be further concentrated. The concentrate from the second stage would then be passed on as feed to the third stage where it would be concentrated to the desired product level. The permeate stream from each stage would be pooled and collected as a single stream.

The stepwise character of staging is clearly shown in Figure 7, which is the flux versus concentration factor profile used in the previous examples adapted to a two stage system. As is shown here, the first stage is used to concentrate the raw whey feed to a concentration factor of 2.6. The flux of

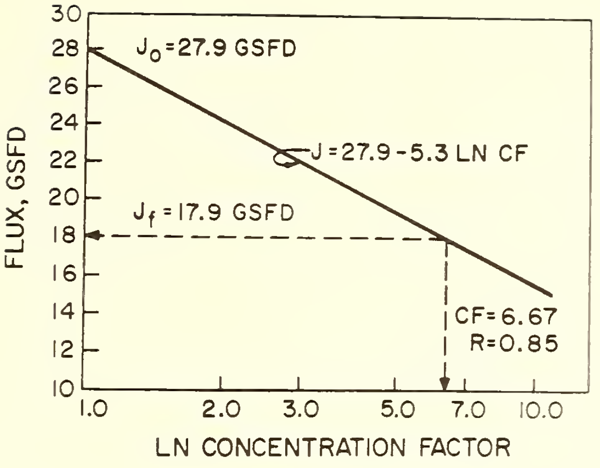


Figure 5.--Example showing how the expected flux of a single stage feed and bleed system is determined from the flux versus concentration factor profile.

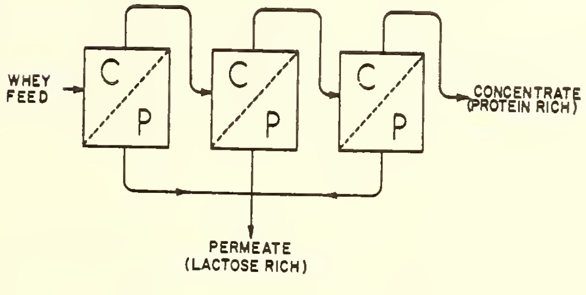


Figure 6.--Schematic representation of a three-stage whey system.

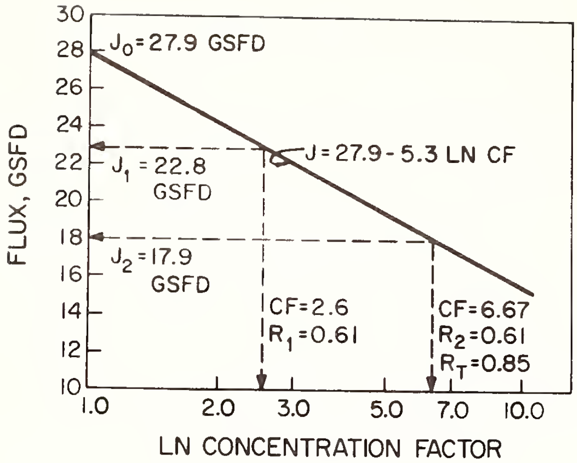


Figure 7.--Example showing how the expected flux of each stage of a two stage feed and bleed system is determined from the flux versus concentration factor profile.

this stage is determined directly from the flux versus concentration factor profile and is 22.8 GSFD, which represents an increase of 27 percent over the flux of 17.9 GSFD that was used throughout in the single stage system. The concentrate from the first stage is then passed on to the second stage where it is concentrated to the desired final concentration factor of 6.67. Obviously since this last stage operates at a concentration factor of 6.67, its flux is 17.9 GSFD. The impact of adding this single stage on the capacity of a feed and bleed system is dramatic because most of the permeate is produced in the first stage. Thus, following the example of Figure 7, if the feed stream was 10 gpm, and the first stage was operated at a concentration factor of 2.6 (or a recovery of 0.61), 6.1 gpm of permeate would be produced as well as 3.9 gpm of concentrate. This concentrate would then be sent to the second stage which, since it is also operated at a concentration factor of 2.6, would result in the production of 2.4 gpm of permeate and 1.5 gpm of concentrate. The overall concentration factor would still be 6.67 as obtained in the single stage system, and 1.5 gpm of product and 8.5 gpm of permeate would have been produced for every 10.0 gpm of feed. However, 6.1 gpm of the total permeate stream of 8.5 gpm would have been produced at the higher flux of the first stage!

The situation can be even further improved by going to three stages as shown in Figure 8. Here the first stage is operated at a concentration factor of 1.9 (or a recovery of 0.47) which gives a flux of 24.6 GSFD, which is 37 percent higher than that obtained as the average flux for single stage system.

It's obvious from looking over Figures 2, 5, 7, and 8 that staging provides a means for approximating the flux profile of batch operation and theoretically, in the limit of an infinite number of stages, would give an average flux synonomous with that of batch. From a practical point of view, however, only a few stages are needed to realize the principal flux advantages of

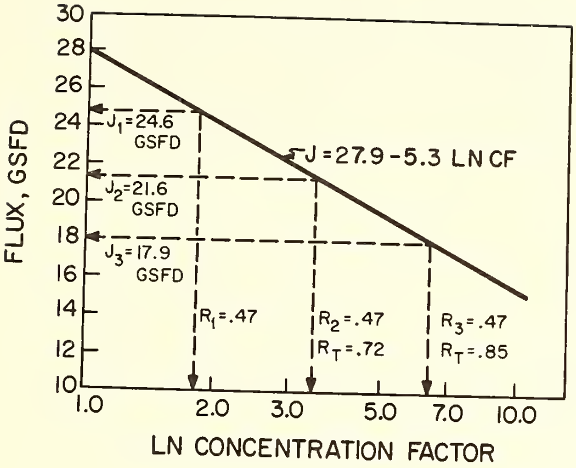


Figure 8.--Example showing how the expected flux of each stage of a three stage feed and bleed system is determined from the flux versus concentration factor profile.

staging. In addition to the dramatic effect that staging has on increasing capacity, it also has a dramatic effect on increasing yields.

YIELD CONSIDERATIONS

The solute yield (Y) of a system is defined as the fraction of the solute retained in the concentrate stream compared with that which was present in the feed stream.

$$Y = \frac{\text{Solute Retained in Concentrate}}{\text{Solute Present in Feed}} \qquad (8)$$

As mentioned previously, this term is not dependent solely on the rejection characteristics of the membrane, but also on the degree of concentration of the feed and the mode of operation of the system, with the mode of operation of the system being perhaps the single most important consideration. Without going into their derivations[6], the yield expressions for batch and continuous feed and bleed operation are given below where the parameters R and σ refer to the permeate recovery and membrane rejection coefficient as defined previously:

$$\text{Batch:} \quad Y = (1-R)^{1-\sigma} \qquad (9)$$

$$\text{Feed \& Bleed:} \quad Y = \frac{1-R}{1-R\sigma} \qquad (10)$$

While these equations are completely different with respect to their functionality, they both give the same limiting yields for the cases where the solute is either completely retained by the membrane (σ = 1.000) or freely passes through the membrane (σ = 0.000). Thus at σ = 1.000, Y = 1.000 and at σ = 0.000, Y = 1-R for both modes of operation.

---

[6] See footnote 4.

These limits mean that the yield is 1.000 or 100 percent for a species that is completely retained by the membrane and equal to (1-R) for a species that readily passes through the membrane. The 1-R yield limit for this latter case perhaps needs some clarification. If a species has a rejection coefficient of 0.000, it would readily pass through the membrane and exit from the system in the permeate stream. Thus, if the system was operating at a recovery of 75 percent (R = 0.75), 75 percent of the solute present in the feed would have been removed from the system in the permeate stream. This means that the amount of solute remaining in the concentrate stream is only 25 percent of the feed, or 1-R.

The yield expressions of equations 9 and 10 are evaluated as a function of recovery and rejection in Tables II and III. Note that for both cases the yield of the system (a) increases as the rejection coefficient increases (horizontal line) and (b) decreases as the recovery increases (vertical line). It is because of this variability that the question "What is the yield of a system?" becomes meaningless unless the system is completely defined. Furthermore, note that the yield of the batch system always equals or exceeds that of the continuous feed and bleed system. Thus batch systems not only give higher capacities, they also give higher yields. However, just as staging compensated for the disparities in capacity, it also compensates for the disparities in yield. The equation for the yield of a multistage feed and bleed system is given in equation 11 where R_1, R_2, R_n are respectively the recoveries of stage 1, 2,...n.

$$Y = \left(\frac{1-R_1}{1-R_1\sigma}\right)\left(\frac{1-R_2}{1-R_2\sigma}\right)\cdots\left(\frac{1-R_n}{1-R_n\sigma}\right) \qquad (11)$$

This equation is evaluated for two and three stage systems in Tables IV and V. As expected, the general trends noted above for the batch and single stage cases are still obeyed, but the yields are higher.

A comparative listing of yields for single stage multistaged and batch systems as a function of recovery is presented in Table VI at three levels of rejection. Note that in all cases staging improves the yield, but that the major impact is in going from one to two stages. As with capacities, an infinite number of stages would be theoretically required for a staged system to give the yields obtained in batch; in practice however, two or three stages can give a very good approximation.

NOTE: These expressions can be written in terms of the concentration factor (CF) as follows:

$$\text{Batch:} \quad Y = CF^{(\sigma-1)} \qquad (9')$$

$$\text{Feed \& Bleed:} \quad Y = \frac{1}{CF - \sigma\,(CF-1)} \qquad (10')$$

TABLE II.--Solute yields (percent) as a function of permeate recovery and membrane rejections batch operation[1]

Recovery[2]	Membrane rejection coefficients						
	0.000	0.100	0.300	0.500	0.700	0.900	1.000
0.100	90.0	91.0	92.9	94.9	96.9	99.9	100.0
.300	70.0	72.5	77.9	83.7	89.9	96.5	100.0
.500	50.0	53.6	61.6	70.7	81.2	93.3	100.0
.700	30.0	33.8	43.1	54.8	69.7	88.7	100.0
.900	10.0	12.6	20.0	31.6	50.1	79.4	100.0

[1] Yields calculated from equation 9.

[2] CF = 1/(1-R).

TABLE III.--Solute yields (percent) as a function of permeate recovery and membrane rejections feed and bleed operation, single stage[1]

Recovery[2]	Membrane rejection coefficients						
	0.000	0.100	0.300	0.500	0.700	0.900	1.000
0.100	90.0	90.9	92.8	94.7	96.8	98.9	100.0
.300	70.0	72.2	76.9	82.4	88.6	95.9	100.0
.500	50.0	52.6	58.8	66.7	76.9	90.0	100.0
.700	30.0	32.3	38.0	46.2	58.8	81.1	100.0
.900	10.0	11.0	13.7	18.2	27.0	52.6	100.0

[1] Yields calculated from equation 10.

[2] CF = 1/(1-R).

TABLE IV.--Solute yields (percent) as a function of permeate recovery and membrane rejections feed and bleed operation, two stages[1]

Recovery[2]	Membrane rejection coefficients						
	0.000	0.100	0.300	0.500	0.700	0.900	1.000
0.100	90.0	90.9	92.8	94.8	96.8	98.9	100.0
.300	70.0	72.3	77.4	83.0	89.2	96.2	100.0
.500	50.0	53.1	60.1	68.6	79.1	92.2	100.0
.700	30.0	32.9	40.2	50.1	64.2	85.3	100.0
.900	10.0	11.5	15.8	23.1	36.8	67.6	100.0

[1] Yields calculated from equation 11 assuming equal recovery per stage.

[2] CF = 1/(1-R).

TABLE V.--Solute yields (percent) as a function of permeate recovery and membrane rejections feed and bleed operation, three stages[1]

Recovery[2]	Membrane rejection coefficients						
	0.000	0.100	0.300	0.500	0.700	0.900	1.000
0.100	90.0	90.9	92.9	94.8	96.9	98.9	100.0
.300	70.0	72.4	77.6	83.2	89.4	96.3	100.0
.500	50.0	53.2	60.6	69.3	79.8	92.6	100.0
.700	30.0	33.2	41.0	51.6	66.1	86.5	100.0
.900	10.0	11.8	16.9	25.5	41.0	76.1	100.0

[1] Yields calculated from equation 11 assuming equal recovery per stage.

[2] CF = 1/(1-R).

TABLE VI.--The comparative effect of staging on solute yields (percent) as a function of permeate recovery and membrane rejections[1]

Recovery[2]	Feed and bleed operation One stage	 Two stages	 Three stages	 Four stages	Batch operation
	Membrane rejection coefficient 0.100				
0.100	90.9	90.9	90.9	90.9	91.0
.300	72.2	72.3	72.4	72.4	72.5
.500	52.6	53.1	53.2	53.3	53.6
.700	32.3	32.9	33.2	33.3	33.8
.900	11.0	11.5	11.8	12.0	12.6
	Membrane rejection coefficient 0.500				
.100	94.7	94.8	94.8	94.8	94.9
.300	82.4	83.0	83.2	83.3	83.7
0.500	66.7	68.6	69.3	69.7	70.7
0.700	46.2	50.1	51.6	52.4	54.8
0.900	18.2	23.1	25.5	26.9	31.6
	Membrane rejection coefficient 0.950				
.100	99.5	99.5	99.5	99.5	99.5
.300	97.9	98.1	98.1	98.2	98.2
.500	95.2	96.0	96.2	96.3	96.6
.700	89.6	92.2	92.9	93.3	94.2
.900	69.0	81.4	84.5	85.6	89.1

---

[1] Yields calculated from equations 9 through 11. Equal recovery per stage assumed for staged system.

[2] CF = 1/(1-R).

PRODUCTION IMPLICATIONS

The implications of staging are perhaps best appreciated when put into a production setting. Comparative data are, therefore, provided in Table VII summarizing the effect of staging on capacity, yield and product solids for a plant designed to produce a whey protein concentrate having a 35 percent protein (TKN) level with 180 HF26.5-45-XM50 cartridges. Operating such a plant as a single stage feed and bleed system would give a capacity of 613,400 pounds per day, a protein yield of 86.4 percent and a solids level of 9.3 percent. By splitting the system into just two stages, with 120 cartridges in the first stage and 60 cartridges in the second, an increase in capacity of 19.9 percent is realized, with a corresponding increase of 6.7 percent in yield at virtually no increment in cost to the dairy. Furthermore, the solids level of the product would have increased 4.3 percent. Going to a three stage system with 90 cartridges in the first stage, 60 in the second, and 30 in the third results in further increases, 5.2 percent in capacity, 1.1 percent in yield, and 2.1 percent in solids, but these are not as dramatic as that which occurred in going from a one to a two stage system. If the protein level of the product was

TABLE VII.--The effect of staging on the production of a whey protein concentrate having 35 percent protein[1]

System[2] design	Capacity[3] lb/day	Protein yield[4] Percent	Solids Percent
One stage (180)	613,400	86.4	9.3
Two stages (120,60)	735,300	92.2	9.7
Three stages (90,60,30)	773,500	93.2	9.9
Batch[5]	839,100	95.0	10.1

[1] Production of a 35 percent protein (TKN) concentrate from cheddar cheese whey using 180 HF26.5-45-XM50 hollow fiber cartridges in the feed and bleed mode of operation.

[2] Numbers in parentheses give the number of cartridges/stage.

[3] Capacity for 20 hour/day.

[4] Yield based on TCA precipitable protein.

[5] Theoretically limiting values for staged systems. (See text for discussion.)

higher (i.e., 50 to 60 percent protein), then additional staging would have a greater impact, but it is really not that critical for a 35 percent protein product. For comparative purposes, performance data are also presented for a batch system under the hypothesis that the system could be operated 20 hours/ day. Since batch operation is theoretically the most efficient mode of operation, these data in essence give the limits that could be reached by adding additional stages. For those dairies interested in batching, these capacities and yields could indeed be realized with, for example, four batches of 5 hours each or two batches of 10 hours each (or any similar combination) provided sufficient tankage was available to allow the ultrafiltration system to go from one batch to another without delay. In practice, however, the batching method of operation for large capacity systems would be economically unattractive.

AUTOMATIC CONTROL

One of the most significant advantages of the feed and bleed method of operation is that it lends itself to automatic control. The method of control could be based on either flow control or on a reading of a unique property of the bleed stream, such as the refractive index. Of the two, flow control is considered more flexible because it allows for routine operation with wheys of variable solids levels.

Flow Control

The control schematic for a generalized continuous feed and bleed system is shown in Figure 9. As shown, the ultrafiltration system operates in a recirculation mode with the bleed stream (or the product stream) taken off of the recirculation loop. From a simple mass balance an expression can be derived relating the performance of the system to the ratio of the flows of two streams. To demonstrate, consider the mass balance of equation 12 where Q_F, Q_B and Q_p are the flow rates of feed, bleed, and permeate streams, respectively.

$$Q_F = Q_B + Q_p \tag{12}$$

Equation 12 simply states that input equals output which is obviously true for any continuous system. Dividing equation 12 by Q_B and rearranging yields equation 14 below.

$$\frac{Q_F}{Q_B} = 1 + \frac{Q_p}{Q_B} \tag{13}$$

$$\frac{Q_p}{Q_B} = \frac{Q_F}{Q_B} - 1 \tag{14}$$

The ratio Q_F/Q_B is simply the concentration factor as defined above. Thus equation 14 becomes:

$$\frac{Q_P}{Q_B} = CF - 1 \qquad (15)$$

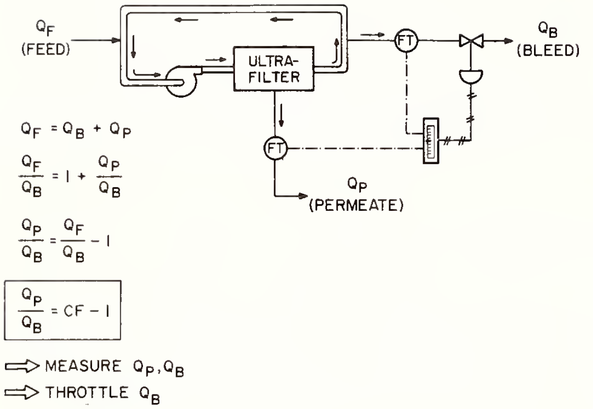

Q_F (FEED)
ULTRA-FILTER
FT
FT
Q_B (BLEED)
Q_P (PERMEATE)
$Q_F = Q_B + Q_P$
$\frac{Q_F}{Q_B} = 1 + \frac{Q_P}{Q_B}$
$\frac{Q_P}{Q_B} = \frac{Q_F}{Q_B} - 1$
$\boxed{\frac{Q_P}{Q_B} = CF - 1}$
⇒ MEASURE Q_P, Q_B
⇒ THROTTLE Q_B

Figure 9.--Schematic illustration showing how flow control devices can be used to control the concentration factor produced in a feed and bleed system.

Equation 15, the basis of flow control, states that in order to continuously produce a product having a specified protein level, as determined by its concentration factor, it is simply necessary to operate the system such that the ratio of the permeate to bleed streams is equal to the specified concentration factor minus one. Thus, to follow the examples given above, if a concentration factor of 6.67 is required to produce a 35 percent protein product, the system should be operated at a permeate to bleed ratio of 5.67. Flowmeters are thus placed in the bleed and permeate lines and signals are generated which allow a continuous determination of the actual permeate to bleed ratio. The observed ratio is then continuously compared with the setpoint and any deviations that occur are corrected by automatically throttling the bleed valve. This method of control is simple and lets the permeate stream run free for maximum capacity while continuously controlling the concentration factor of the product stream (protein level). Furthermore, as indicated by the flux versus concentration factor profiles of Figures 5, 7, and 8, this method of control should yield a relatively constant system capacity over the course of the day's run. Thus, once the specified concentration factor is fixed, the expected flux should also be fixed which relates to the capacity of the system. That this surprising result is indeed observed is shown in Table VIII which contains capacity data collected over a 3-day test period on a 120 cartridge production system operating on cheddar cheese whey. This system was a manual system, but it was operated with very close control of the permeate to bleed ratio during the test period. The setpoint used was a permeate to bleed ratio of 4.9 (i.e., a concentration factor of 5.9) which gave a product containing 35 percent protein (TKN) with this whey. As is shown in Table VIII, extremely

TABLE VIII.--Capacity stability study on a production system operating in the feed and bleed mode[1]

Day 1		Day 2		Day 3	
Time	Capacity, lbs/hr	Time	Capacity, lbs/hr	Time	Capacity, lbs/hr
0807	19,630	0742	21,130	0752	21,120
0907	19,300	0915	19,340	0900	19,790
1015	20,490	1000	20,300	1015	20,240
1100	19,630	1100	18,020	1200	21,280
1200	18,720	1215	19,030	1430	19,150
1247	19,980	1330	18,800	1630	19,760
1420	19,900	1645	19,670	2025	18,650
1451	19,010	2015	17,760	Ave.	20,000
1523	20,230	Ave.	19,260	CV[2]	4.8
1815	19,800	CV[2]	5.8		
1854	19,250				
Ave.	19,630				
CV[2]	2.7				

[1] 120 HF26.5-45-XM50 hollow fiber cartridges operating on cheddar cheese whey.

[2] Coefficient of variation ($s/\bar{x} \times 100$), percent.

uniform capacities were achieved throughout the day with the maximum variation being 5.8 percent. Over the 3-day test period the average system capacity was 19,615 lbs/hour with a coefficient of variation of just 4.5 percent. In spite of the relatively constant capacity indicated by these data, it should be mentioned that this is not an automatic result and that the principal factor determining the extent to which the capacity of a recirculating feed and bleed system would drop during a day's run is the character of the feed stream supplied to the system. Clarified fresh whey should give relatively high and constant fluxes as indicated above. However, if the whey contains fat or is allowed to stand which could result in changes in acidity, etc., a capacity decrease during the day will certainly be observed.

The stability of flux with time observed with whey is also observed with skim milk as shown in Table IX. These data refer to a pilot feed and bleed run using fortified skim milk having an initial protein level of 3.5 percent and a solids level of 9.9 percent. The system was run over a 7-hour period at a concentration factor of 3.0 ± 0.2 which produced a milk concentrate of 10.7 percent protein and 16.7 percent solids. The flux realized during this test was 12.69 ± 0.25 GSFD for a coefficient of variation of less that 2 percent. These data indicate that the solids level per se, as long as the system is recirculating, do not have any bearing on control. Obviously this conclusion may not apply to single pass or nonrecirculating systems which may indeed become seriously fouled with high solids streams.

TABLE IX.--Flux stability study for a single cartridge system operating in the feed and bleed mode on fortified skim milk[1]

Elapsed time, hours	Flux, GSFD	Solids, percent	Protein (TKN), percent
0.0	-	9.90	3.50
2.1	12.7	-	-
2.5	12.4	-	-
2.6	13.2	-	-
2.8	12.7	-	-
3.4	13.2	16.7	10.4
3.8	12.7	-	-
4.4	12.7	-	-
4.7	12.7	-	-
5.0	12.7	-	-
5.2	12.4	-	-
5.4	12.4	-	-
5.8	12.4	-	-
6.6	12.7	-	-
6.9	12.7	16.6	10.9
7.1	12.7	-	-

[1] This study consisted of a single HF15-45-XM50 hollow fiber cartridge operating in the feed and bleed mode at a constant concentration factor of 3.04.

Variable Solids Feed

One advantage of ratio control is that it allows the system to operate on feed streams of variable solids with no change in setpoint, because in ultrafiltration, the presence of water has no bearing on the composition of the product produced unless it affects solute-solute interactions such as protein-ash binding[7]. Assuming this not to be the case, if a product is produced from raw whey at a specific concentration factor, the same product will also be produced from condensed whey as long as the concentration factor does not change. This is illustrated in Table X which shows the concentration factor needed to produce a 35.1 percent protein product as a function of the solids level of the feed stream. Note that the only differences in the composition of the feed is in the amount of water present. The implication of this result is that if ratio control is used, systems could be designed to operate with a variable solids feed stream (Figure 10). Thus, a condensed whey of 30 percent solids could be continuously mixed with a raw whey of 6.5 percent solids to produce an intermediate solids stream which is fed directly to the ultrafiltration system. Throughout this operation the setpoint for the permeate to bleed ratio would remain unchanged despite the variable nature of the solids feed. Admittedly the level of solids in the feed will affect the capacity of the system, and this should be optimized, but it will not affect the composition of the product being produced.

---

[7] See footnote 4.

TABLE X.--The effect of feed stream solids on the control setpoint for the production of a whey protein concentrate having 35.1 percent protein

Species	Raw whey[1] 6.5 percent solids	Condensed whey 20 percent solids	Condensed whey 30 percent solids
Protein (TCA ppt.), lb	0.500	1.538	2.308
Non-protein nitrogen, lb	0.300	0.923	1.385
Protein (TKN), lb	0.800	2.461	3.693
Lactose, lb	4,900	15,077	22,615
Ash, lb	0.800	2,462	3,692
Solids, lb	6,500	20,000	30,000
Water, lb	93,000	80,000	70,000
Mass basis, lb	100,000	100,000	100,000
Recovery, percent	84.6	84.6	84.6
Protein (TKN), percent	35.1	35.1	35.1

[1] This column gives an assumed typical composition of cheddar cheese whey. This composition was used as the basis for the compositions of the condensed wheys.

The ability to operate a system in this manner is especially important in areas where a separate whey processing facility has been set up to handle

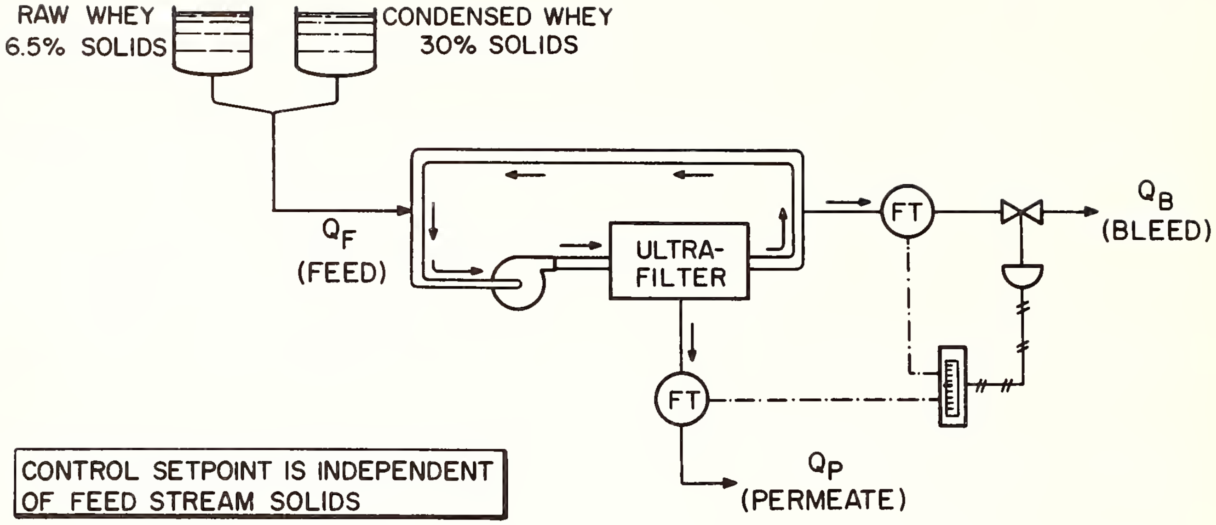


Figure 10.--Schematic illustration showing how a feed and bleed system, with flow control, can be used to continuously process feed streams of variable solids levels.

large quantities of whey provided from a number of regional dairies. Obviously, when transportation costs have to be considered for such dairies to condense the whey before transporting, it is often economically advantageous. The central processor then has the option of diluting the whey with water, which would be economically unattractive since the water will have to be removed eventually, or diluting it with raw whey to lower the solids and improve the capacity of the ultrafiltration system. This latter route is certainly more attractive.

Refractometer Control

Perhaps the simplest method of automatic control is the use of a refractometer in the bleed stream to maintain a specific solids level. The control schematic is basically the same as illustrated in Figure 10, with the permeate flow transmitter eliminated and the bleed flow transmitter replaced with a continuously reading refractometer. Deviations in the solids level of the bleed from the setpoint are used to throttle the bleed stream. This method of control obviously cannot handle variable feed solids, but it certainly would work with a specific type of feed. The main limitation of this method of control is in the reliability of the refractometer, a concern that must be faced with any analytical instrument that is going to be used as an on-line monitor of the composition of the bleed stream.

SUMMARY AND CONCLUSIONS

Review recent developments in ultrafiltration processing technology, which are of particular significance to applications in the dairy industry, was the objective of this paper. While the discussion was intentionally general, a number of key points were brought out, the most important of which are listed below.

1. The capacity and yield of a system are significantly affected by the mode of operation, the degree of concentration, and the rejection characteristics of the membrane.

2. The most efficient mode of operation, based on capacity and yield, is batch. Batch systems, however, suffer from prolonged resident times which could lead to microbial contamination. They also are labor intensive and require excessive tankage for large-scale operations.

3. Continuous feed and bleed systems are inherently less efficient than batch systems with respect to capacity and yield, but they can be made to approach batch by staging. Their advantage over batch is that they operate with extremely low resident times, typically minutes, which greatly reduces the possibility of microbial contamination. They also lend themselves to complete automation and require minimum tankage for large-scale operation.

4. By operating with recirculation, continuous feed and bleed systems can be used to produce whey protein concentrates of relatively high protein levels and are not limited to a 35 percent protein product. Furthermore, by employing ratio control techniques, they can be designed to handle feed streams with variable solids.

ACKNOWLEDGMENTS

The technology discussed in this paper is the result of the combined efforts of both the Process and Engineering groups at Romicon. While a number of people played important roles, the efforts of Brian M. Kilcullen, Darrell F. Quinn, Arie Keus, and Ernest Beauregard should be particularly recognized.

QUESTION: My name is Edward Green, Milk Marketing Board, United Kingdom.

I am a little concerned since I came over to the USA to learn that insofar as ultrafiltration is concerned, the solution to the whey problem appears to be the production of a whey powder containing 35 percent protein which is going to substitute for skim milk powder, in other words, solving the problems of one side of the dairy industry by creating problems on another.

In our view in the United Kingdom we should not be doing this type of thing. We are, for example, investigating an ion exchange or a form of ion exchange as a system of introducing protein with a powder with a whey protein content in excess of 90 percent. The Viscose Company in the UK have a patent for doing this and we are working in conjunction with them.

We find this protein has specific functional properties as a replacement for egg albumin, and there is every indication the market value of this can well be in the region of about 200 cents per pound or thereabout, and I would be interested to know whether there is any work going on in the USA on these lines.

I would like to make another point. We have an ultrafiltration plant in which in two stages we are producing a powder which has a protein content of 65 percent, and this has every indication of being of value in the baking industry because of its functional properties, but I am not talking here of a replacement for skim milk powder, but as a replacement for whole egg, and the indications that we have so far are that this may well have a value in the region of a hundred cents a pound or thereabouts.

So I am saying to the cheese industry, let's turn our attention away from a replacement of skim milk and be looking in other fields.

DR. BRESLAU: The point is of course well taken, but I would like to make a comment in support of some of the dairy manufacturers in the USA. While we use the 35 percent product as a standard by which we design a system or set up how to put a system in or demonstrate what the product capabilities are of ultrafiltration, I have found over the past year, that most of the industry interest at least directed to us at Romicon, is certainly not at 35 percent product, it is indeed much higher protein.

ADAPTION OF UF TO WHEY PROCESSING

O. J. OLSEN

DDS RO-Division
The Danish Sugar Corp., Ltd.
DK-4900 Nakskov, Denmark

INTRODUCTION

Denmark is (1) a dairy country and (2) has no problems with drinking water pollution. These two factors have contributed to (beginning in 1965) the development in Denmark of the membrane processes--reverse osmosis (RO) and ultrafiltration (UF)--have had a different goal than the original one in the United States, where desalination of sea and brackish water from the beginning had the attention of the authorities empowered to make grants. I am fully aware that the situation in the United States today is different.

At DDS, however, from the very beginning we have had our eyes focused on the dairy industry as a potential user of membrane equipment. However, had we known from the start that the demands this industry would make on us, it is doubtful whether we would have tackled this field.

I shall give a summary of the historical development that has led us to our present position. We decided to develop equipment where the system and the membranes could be developed independently, since we believed that in the United States, you were ahead of us as far as membranes were concerned. We wanted to have the opportunity to use foreign membranes in our own system; however, the result turned out to be quite different.

We were not too interested in the desalination of water but mainly in the treatment of dairy products. This meant that from the beginning we were aiming at the sanitary design without having 3-A Standards in mind, but what we considered to be sanitary. We developed a system based on the plate-and-frame principle, made of die-casted plastic and stainless steel. Our membranes were made of cellulose acetate. Special cleaning procedures with detergents containing enzymes, rinsing with citric acid, and disinfecting with weak Cl_2 solutions were developed as the CA membrane only withstands Cl_2 to a limited degree.

We presented this system to The Danish Government Research Institute and asked for a statement, which we received according to the following:

> "Before you manufacture ultrafiltration plants totally of stainless steel, inclusive of the membranes, you shall not expect the dairy industry to employ these systems, with all their plastic and paper."

This was the result of 5 years of work. The statement was a blow for us, but at the same time a challenge which we thought should be considered. The system was certainly not as bad as it was interpreted to be. Today, many plants throughout the world operate with this system and you just have to know its limitations and demands on careful tending with regard to cleaning.

SECOND GENERATION

Demands on our second generation UF system were made as follows.

1. Defective membranes should be easy to trace.
2. Defective membranes should be easy to change without interfering with other membranes.
3. Using the same cleaning and disinfection procedures as are normally applied within the dairy industry should be possible.
4. Failure in temperature of pH control must not cause destruction of the plant or membranes.

Point No. 1 is easily obtained by leading permeate or filtrate seperately from each membrane support plate and collecting it in an external joint tube. It will then be easy to locate the defective membranes (as the permeate will be very turbid).

Point No. 2 was solved by compressing the system between two end flanges, as in the plate heat exchanger, which were connected with two external bolts. A membrane can then easily be taken out by loosening the bolts and simply taking out the defective membrane plate.

Point No. 3 was the most difficult, but here the development within the polymer industry came to our aid as the material, polysulphone, was gradually manufactured in such large quantities that the prices and delivery conditions were acceptable. We, therefore, manufactured all our plastic material of polysulphone which in many respects possesses qualities as good as and in some ways even better than stainless steel. The material is listed in 3A's records under No. 2005, so it causes no problems when applying it in the dairy industry.

The membranes have always been the weak point in every membrane filtration system. However, we have succeeded in manufacturing a membrane that fully meets the demands from the dairy industry with regard to acid and alkaline cleaning agents. The membrane is made of a highly resistant polymer, cast on a support of polyesther or polypropylene, so that the mechanical strength is very high. The ultimate strength is approximately 100 pounds per inch.

The chemical resistance of the membrane, type GR versus cellulose-acetate, is shown in Table I. With regard to temperature, there are no practical limits, as the whole system can operate on boiling acid or alkaline cleaning agents. However, certain reservations must be made against chlorine containing products, as these may cause corrosion of the stainless steel.

TABLE I.--SPECIFICATIONS

	With CA* - membranes	With GR - membranes
pH-range	2-9pH	0-14pH
Temperature range	Max. 50° (max. 122°F)	Max. 100° (max. 212°F)
Pressure range	0-10 bar (0-140 lbs/sq.inch)	
Max. allowable conc. of:		
Sodiumhypochlorite	0.002%	2%
Hydrogenperoxide	1%	10%
Aliphatic alcohols	20%	no limit
Acids	min. pH∿3	no limit
Alkalis	max. pH∿9	no limit
Phenol, aliphatic hydrocarbons	must be avoided	no harmful effect
Keytones aromatic and chlorinated hydrocarbons	must be avoided	

*CA: cellulose acetate

PRETREATMENT

Our experiences with ultrafiltration of whey are varied. However, they have given us quite a clear knowledge of the importance of the pretreatment. Today, intensive work is being done in many places throughout Europe with the development of pretreatment methods which affect the final product and the capacity of the ultrafiltration plant.

At the Dutch Experimental Institute, NIZO, Dr. de Boor is working on a method for complete removal of fat from the whey before ultrafiltration. This has a most favorable effect on the capacity of the UF plant by obtaining a whey protein product which is practically fat free. This means these proteins can be whipped and thus to a full extent, substitute for hens egg whites for many purposes, for example, meringues. Unfortunately, details on this interesting subject will not be released until the first few months in 1977.

Another pretreatment method that has been studied and tested at the French Research Center, I.N.R.A., under the leadership of Dr. Maubois, is preconcentration by evaporation before ultrafiltration. The result is, among other things, a considerable increase in capacity of the UF plant. The capacity is shown in Figure 1. This curve shows the conditions when you want to make a product with 35 percent protein in the total solids, i.e., a skim milk substitute. As it appears here, the maximum capacity is obtained by a preconcentration to 20 percent TS. Converted into whey with 6 percent TS as initial product, a capacity of 120 gallons whey/sq. ft./day is obtained. As a comparison, at cold temperature operation (50 to 59° F) on the same product the capacity is approximately 24 gallons whey/sq. ft./day. Whether these very high capacities can be obtained under conditions operating for a prolonged period of time, I am unable to say, as these trials are rather short-time batch trials. However, it implies the possibility of obtaining capacities so far unknown. The advantages of this preconcentration are that you also obtain a permeate with a total solids of 17.9 percent and a concentrate of 27.9 percent total solids; for the latter, this means you can proceed directly to spray drying of the product.

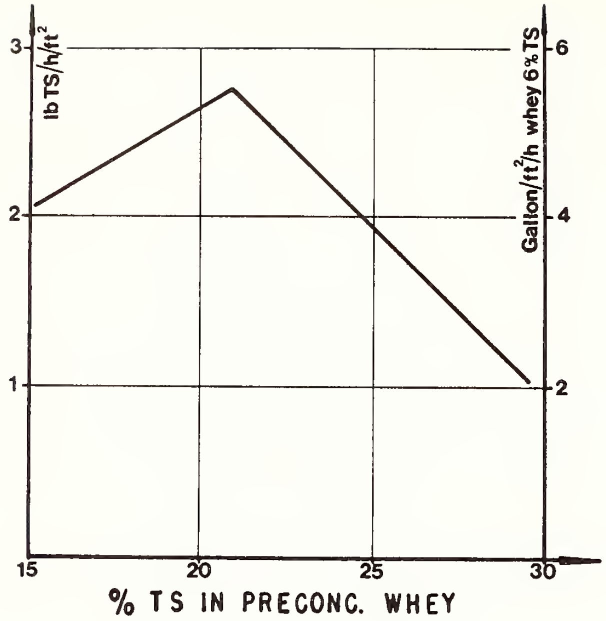


Figure 1.--Influence of whey preconcentration on UF plant output.

TABLE II.--Production of 35 Percent Whey Proteine

Prevaporated Whey	Proteine Concentrate	Permeate
% TS	% TS	% TS
18	25	15
20	28	18
27	35	24
28	35	25

CONSTRUCTION OF THE PLANT

Production plants for UF of whey will always be made as continuous systems, which means that the residence time of the whey in the UF plant can be made very short, provided the internal volume is small. The internal volume per square foot membrane in the UF module itself is 0.012 gallons per square foot as shown below:

TABLE III.--INTERNAL VOLUMES

In the module, conc..........	0.012 gal/ft^2
In the module, permeate......	0.017 gal/ft^2
Total Plant, incl. feed tank	0.085 gal/ft^2
500.000 lb/day plant	

However, this value is not very interesting, as a UF plant consists of more than the modules; a more relevant value is volume/square foot in the total UF plant, i.e., inclusive of external pipes and pumps. For a fairly large production plant, this value is 0.08 gallons/sq. ft. membrane, and this value compared with the capacity of the plant gives the residence time. Figure 2 shows the result of a practical test made on a plant with a total membrane area of 3,600 sq. ft., with the average residence time for the concentrate approximately 11 minutes and after 28 minutes, the last trace of the reference matter has left the plant. The residence time on the permeate side is relatively short. This is of great importance, as problems with the growth of mold or yeast in the membrane support material may otherwise easily occur. This, in connection with the new cleaning methods with a strong alkaline cleaning agent at approximately 170°F has completely eliminated this problem from our system.

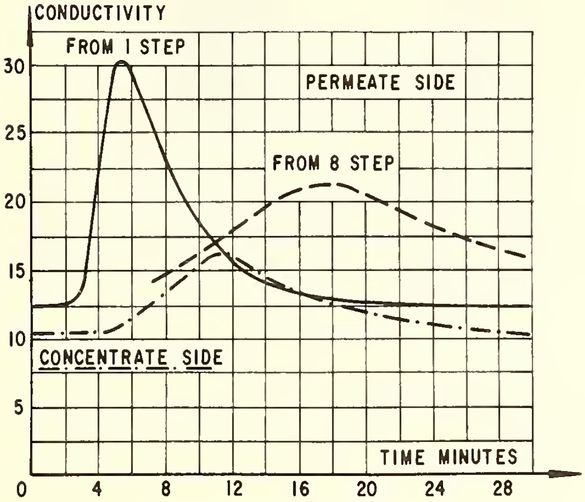


Figure 2.--Retention time of a 500,000 lb/day UF plant.

HOW DO WE DESIGN PRODUCTION PLANTS?

Figure 3 shows how continuous plants are built. Today, this principle is used by all UF equipment manufacturers.

There are two ways to control the composition of the final product: (1) a simple volumetric control--one flow meter measuring the whey flow to the plant and (2) another flow meter measuring--and regulating the concentrate outlet in a certain ratio to the whey inlet, the so-called ratio controller. From Figure 4 you will see the relationship between the concentration ratio and the composition of the final product, expressed as protein in TS. Provided with a uniform whey quality, it is possible to produce any whey protein powder up to approximately 70 percent protein in TS by a simple conversion of the ratio controller. If you wish to go further,it will be more advantageous to perform a washing out or a diafiltration, a refractometer control

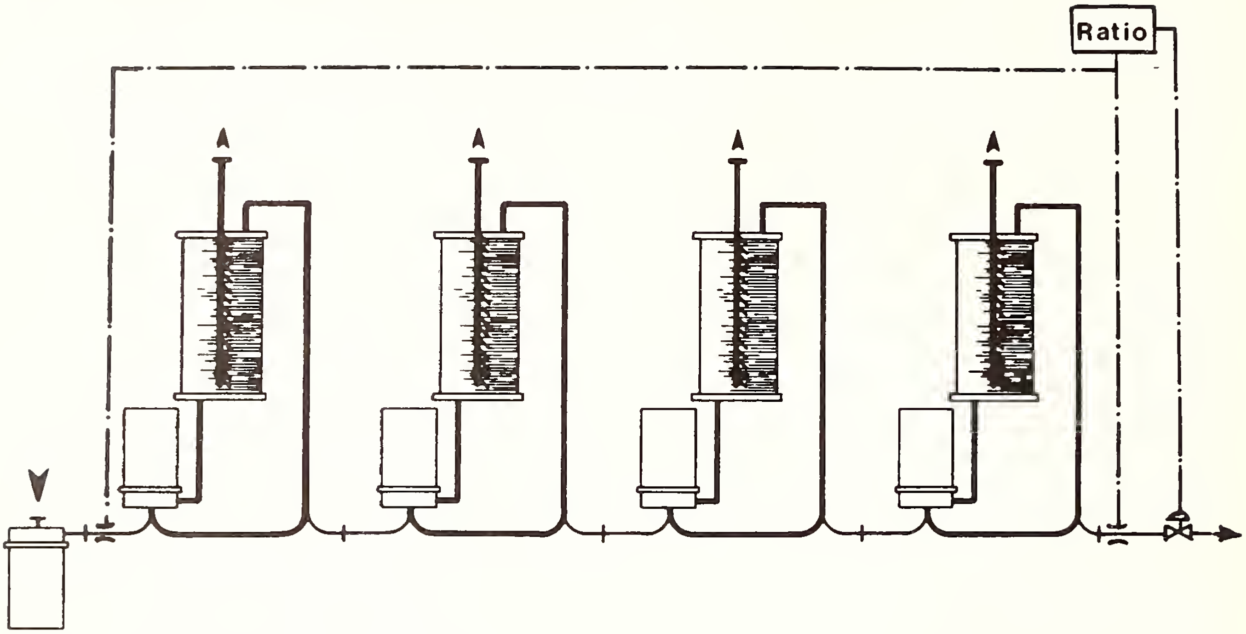


Figure 3.--Continuous UF plant, module type 35.

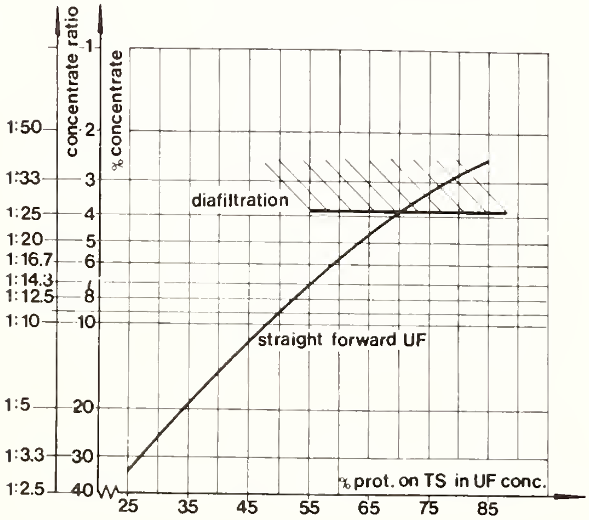


Figure 4.--Relationship between concentration ratio and final product composition.

(Figure 5) of the concentrate. There is a relationship between TS and protein in TS (Figure 6). The refractometer offers considerable advantages. Already at start-up the first concentrate leaving the plant has the correct composition. When the product is pushed out before cleaning, you can obtain a correctly composed concentrate to the very last. Process refractometers have previously been of an unsatisfactory quality, but it looks as if the development has now given us reliable instruments. We now have eight refractometer controlled plants in operation, and there have only been minor problems with these. In the future we will, therefore, probably to a large extent let the volume controller be replaced by the refractometer.

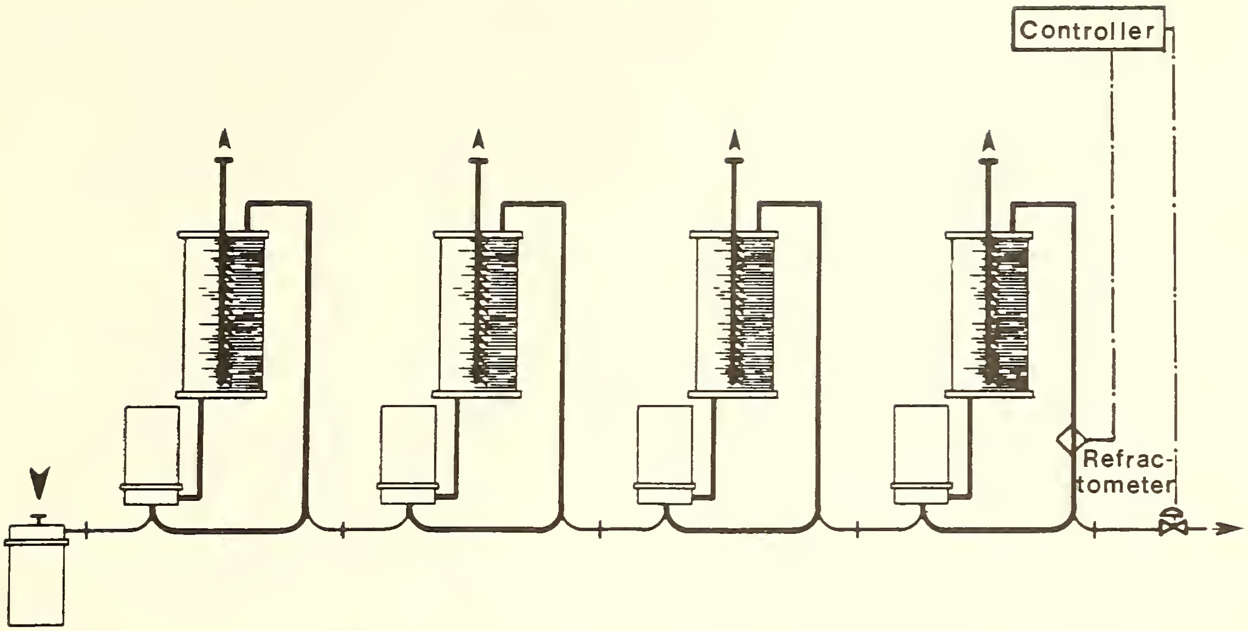


Figure 5.--Continuous UF plant module type 35 with refractometer control.

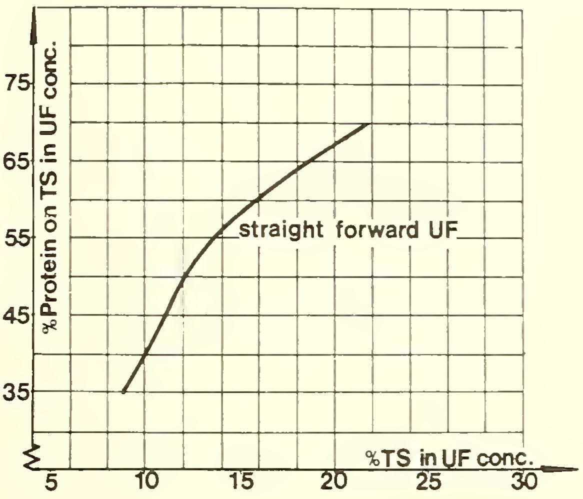


Figure 6.--Relationship between total solids content and percent protein.

Furthermore, the plants are today automated to such a degree that they can operate without constant surveillance also during CIP cleaning. We find it most essential to eliminate the human factor as the failures that may occur in a UF plant are often due to operating errors or just laziness. If an operator has the night off after he has cleaned the plant late in the evening, it is tempting to shorten the cleaning procedure or skip some procedures. With a fully automatic CIP cleaning, we have solved this problem.

A comparison of today's cleaning procedures for UF with that for a plate heat exchanger is shown in Table IV.

TABLE IV.--Comparative data for ultrafiltration and plate heat exchanger operations.

	UF	PHE
Step	UF Plant	Plate Heat Exchanger
1	Rinse with water	Rinse with water
2	Recycle HNO_3 sol.	Recycle alkaline Detergent 170 degree F
3	Rinse with water	Rinse with water
4	Recycle alcaline Detergent 170 degree F	Recycle HNO_3 sol.
5	Rinse with water	Rinse with water
6	Disinfection E.G. Chemicals, hot water	Disinfection E.G. Chemicals, hot water
7	Rinse with water	Rinse with water

SANITARY CONSIDERATIONS INVOLVED WITH ULTRAFILTRATION EQUIPMENT

R. G. SEMERAD

Agricultural Marketing Service, USDA
Washington, DC 20250

The prospective purchaser of ultrafiltration equipment will probably have a long checklist to help in making the decision. The list will surely include items such as cost, capacity, space required, reputation of the manufacturer, delivery time, membrane performance, and last but certainly not least, sanitary considerations.

The dairy plant manager or sanitarian, after years of experience with stainless steel, looks at the various kinds of UF equipment and finds that his previously tried and true sanitary yardsticks don't apply. I heard a comment recently that UF processing "Seemed like running whey through a piece of mush and then trying to clean the mush afterward."

Actually, UF equipment is quite sophisticated and has been specially designed to do a special job and to do it in a sanitary manner. Our work with manufacturers of this equipment began in 1971 with consultation about sanitary design. The membrane equipment industry had industrial and some food experience, but wanted to know the sanitary design requirements for dairy applications, especially for whey processing. Upon request, we evaluated a company's equipment and made recommendations when applicable.

At this point, it might be germane to explain that a high percentage of the cheese factories and whey drying plants in the country have voluntarily requested USDA Inspection of their processing operations. These plants represent the largest potential market for UF equipment. The plant managers are understandably interested in the USDA attitude toward new equipment before they decide to buy it. The membrane equipment manufacturers are similarly motivated to avoid expensive design changes after new equipment is introduced in the marketplace. Speaking for USDA, we are pleased to check sanitary aspects of equipment beforehand. For all parties concerned, making changes at the "blueprint" stage of equipment development is much more practical. We like to get involved early for another reason--to learn from the industry and to prepare ourselves for the upcoming inspection responsibility.

Some of the new UF equipment required only minor changes while others needed major redesign and remodeling. Excellent response has been received from the manufacturers. I would like to share with you the guiding principles we are using in reviewing membrane equipment for sanitary considerations:

1. We let the company do the designing and engineering. USDA activities are confined to comments and constructive suggestions. Clear definition of the sanitary problem is usually sufficient to elicit ideas for correction from the design engineers.

2. We work constructively with the basic design proposed by the company rather than steering them to an alternate basic approach. By their evolution of a design, management has strong convictions tying them to that concept. They know the strengths and limitations of the equipment and can usually act rather quickly in making necessary modifications.

3. Each company is asked to determine compliance of all nonmetallic construction materials with the applicable FDA Regulations.

4. 3-A principles of sanitary design are applied wherever they appear to be applicable and practical. Management is advised that USDA guidance is given entirely independently of the 3-A organization, and it is possible that this guidance may conflict with subsequent 3-A determinations.

5. Components of membrane equipment for which there are 3-A standards (pumps, valves, etc.) are required to meet the 3-A requirements.

6. The entire system is checked carefully for elimination of "dead ends" or dead end flow conditions.

7. It is strongly recommended that each system be equipped with automated controls or programmer to protect against adverse operating conditions and to handle the cleaning and sanitizing regimens in a predetermined manner.

8. We have not favored any one of the three types of systems. There may be useful dairy applications for the batch, semibatch, and continuous "feed and bleed" methods of operation.

9. The membrane review work has been done under the premise that the system can be designed to operate without appreciable propagation of bacteria in the retentate so that preservatives (such as hydrogen peroxide) would not be necessary. It appears that this will be a valid concept. So far, we see no necessity for a general sanction of this "ace-in-the-hole" which could be permitted as a processing aid under certain circumstances. Hydrogen peroxide has been permitted by both FDA and USDA for batch-type electrodialysis processing of whey because it appears to be necessary to avoid bacterial growth in the product during the 2 to 5 hour period of batch recirculation. Of course, the peroxide is not allowed to be a substitute for sanitary conditions and it must be subsequently dissipated to prevent residues in the finished product. It is possible that batch type UF processing will require peroxide use under a similar rationale, but so far batch UF processing is not a popular procedure.

10. It is recommended that the pasteurization step precede UF processing of whey; however,, we are amenable to other locations for the pasteurizer for technological reasons, such as processing acid-type whey or tailoring the whey fraction for special uses.

11. We are likewise open to considering all factors involved in determining what the fluid product temperature should be during processing. The initial bacteriological quality of the product and the average retention time in the system are perhaps the primary factors. The aim, of course, must be to consider all factors so that bacterial growth is controlled.

12. Consideration is given to the sanitary handling of the UF permeate in the equipment as well as the retentate fraction. This approach then permits human food use of the permeate solids without any further sanitary modifications of the UF equipment. This approach has been well received by all the manufacturers we have worked with.

13. USDA has not taken positions regarding nonsanitary controversies such as:

    (a) Cellulose acetate vs. noncellulostic membranes
    (b) Membrane life
    (c) Cost of the equipment
    (d) Conventional vs. enzymatic cleaners

14. Determinations are made through various combinations of blueprint and equipment review, company research data, laboratory testing, and commercial use observations.

    The manufacturer must demonstrate that the equipment can be repeatedly cleaned in a satisfactory manner through use of the chosen cleaning regimen.

15. Information learned in confidence is maintained confidential. Any items presented here today are openly discussed by company representatives and salesmen. However, we have assured manufacturers that we will not reveal private information about new membranes, systems under development, etc.

As I said before, we have had excellent response from the membrane equipment manufacturers. They realized that their equipment for paint purification, desalination, and other industrial and food purposes could not be expected to satisfy dairy sanitation requirements. They readily moved ahead with major redesign changes when needed in order to produce tailor-made equipment for the dairy industry. To date, the following six companies, listed in alphabetical order, have letters rating their UF equipment satisfactory for use in a USDA approved plant:

1. ABCOR, INC.

   This is a tubular type unit, with the membrane inside the porous tube. A number of tubes are mounted in a stainless steel cabinet very similar to a cabinet type surface cooler. The cabinet also has a trough on the bottom to catch the permeate.

2. DANISH SUGAR CO. (DDS-RO DIVISION)

   This is a plate and frame type equipment and the latest design has a horizontal configuration (formerly were stacked vertically).

Sheet-type membranes are pressed into position between hard plastic perforated hollow plates. Permeate is removed from each plate with a small diameter flexible tube.

3. DORR-OLIVER INC.

Membrane material is cast on all sides of thin plates, 30 plates per cartridge. Permeate travels inside each plate through porous material to a common "header" section of the cartridge. Cartridges are located inside square stainless steel tubes. Whey is circulated through them at high speed. Permeate is removed through special fittings from each cartridge.

4. ROMICON INC.

This is "hollow fibre" equipment, with the fibres encased in a plastic cartridge. Fibre lumen diameter is 0.020 or 0.045 inches, with the latter most commonly used for whey processing. Backflushing is possible with this equipment during the cleaning regimen.

5. TRI-CLOVER-THOMAS

Sheet-type membranes are spirally wound around a central hollow tube for permeate removal. Modules either 25 or 39 inches long are encased in stainless steel tubes for whey recirculation.

6. UNION CARBIDE (FORMER WESTINGHOUSE TECHNOLOGY)

This is a tubular concept, with 18 approximately 1/2-inch diameter tubes embedded in a resin-sand mixture inside a stainless steel shell 4 ft. long. Flanged fittings and gaskets are provided for connecting modules in series. Permeate travels through the porous resin-sand matrix to a center located, perforated permeate collection pipe.

Another company, Aqua-Chem Inc. of Milwaukee is currently working with us toward acceptance of a new plate and frame-type unit intended for sale to the dairy industry. Testing and evaluation is still in progress.

UF units recently installed are of the continuous type (rather than batch type) and have continuous whey in-feed and bleed-off of finished product. Temperature of operation varies from 68°F up to 125°F. Concentration of protein is usually to the level of 35 percent (dry basis), although, of course, the equipment is capable of much higher levels.

Most of these companies have pilot models for R & D work, but there is no problem in designing and building high capacity UF systems capable of handling 50,000 pounds per hour or considerably more with multiple units. In fact, the commercially installed UF systems in the United States already have the capacity to handle 3-1/2 billion pounds of whey annually, over 10 percent of the total available. This amount of whey would yield about 57 million pounds of dry whey protein concentrate containing 35 percent protein.

As of October 1, 1976, four of these whey UF plants are USDA approved. Some additional requests for inspection and approval are pending, so we expect the list to grow.

What do we look for on these plant inspections? First of all, we check that all of the whey originates from approved cheese factories. Any handling, transportation, and storage must be conducted in a sanitary manner by using equipment meeting the same requirements as those applicable for milk. Sweet whey must be promptly processed, or if this is not possible, it must be heated and held at 145°F or cooled and held at 45°F. (The heating option may not be too practical because of the denaturing of whey proteins.) In the UF process itself, we are interested in the processing temperature and the average retention time at each step in the process. We check for pasteurization with 3-A equipment and procedures at a suitable point in the processing. We check cleanliness of the UF equipment itself by three main procedures: (1) dismantling and visual inspection, (2) review of company control of daily cleaning operations based on adherence to procedures recommended by the equipment manufacturer which have been demonstrated to be effective, and (3) review of flux rate tests after cleaning. As a fourth yardstick of cleanliness, we think there is some promise in a procedure of relating the dissipation of the sanitizer solution to equipment cleanliness. However, we don't have a formula or practical way of applying the idea during plant inspections. The concept would make an interesting research project.

As mentioned previously, we strongly recommend that the cleaning regimen be automatically programmed, preferably to be backed up by a recording thermometer record of operating times and temperature and cleaning regime conditions. This can be invaluable in detecting irregular operating conditions or variations in the cleaning regimen.

In 1974, the Dairy Division recommended that a 3-A sanitary standard be developed for membrane-type dairy equipment. We are pleased that this work has been undertaken by the 3-A committees and that a user group task committee is now busy on the project. Hopefully we'll have a standard within 2 years. When this occurs, the prospective buyer would be well advised to look for the 3-A symbol on membrane equipment, just as he does on conventional dairy equipment.

Although membrane whey processing is in its infancy in this country, we should be mindful of the likely market for the final product. The long-range future of whey protein products probably lies not in primary utilization for nutrition, but in tailor-made whey products that will enhance the flavor, whipability, waterbinding, stability, etc., of other foods. To gain wide acceptability as a wholesome, nutritious food ingredient that has other special attributes poses a problem with the current image of whey as a "byproduct." Many factors have helped create this attitude. Changing it will not be easy. In the area of sanitary considerations, our new membrane processing plants are aimed at upgrading the image so that whey protein concentrates can stand shoulder to shoulder with other dairy products. USDA stands ready to assist in achieving that goal through review of equipment, surveys of processing operations, and inspection of finished product.

QUESTION: Do you have a count of the actual number of installations of membrane units in plants across the United States representing either approved or unapproved installations?

MR. SEMERAD: I think it would be roughly about two dozen.

QUESTION: You said something in your speech about FDA and its relationship to your approved plants. Now, can you elaborate on that? Is that FDA approved installation?

MR. SEMERAD: My reference was to the requirement for USDA approval of the equipment that the nonmetallic construction materials must meet Food and Drug requirements. They have requirements for the repeated food use contact materials, and depending on their class, specified tests are outlined for determining their safety with respect to toxicology and bleaching out and so forth. That was my reference.

Now, perhaps what you have in mind is an entirely different matter, that is, the requirements of the Grade A Inspection Branch of the Food and Drug Administration, and I cannot speak for their requirements. We are separate agencies.

But the matter has come up recently in connection with the possible use of ultrafiltrated fractionation in Grade A fluid products, and the requirements for this will, I understand, require evaluation by this agency of the same equipment. They have just begun to be interested in that area.

It was my hope and I believe the hope of many in the industry that the 3-A standards for membrane equipment would have been promulgated before this interest came about, but it hasn't worked out that way. My feeling in that direction was that the Grade A authorities have direct input into the 3-A function, and any equipment standard is acceptable to them. But what this means is that they will review this equipment separately to some extent, and I'm not sure at this stage what additional requirements, if any, will be asked for by them.

QUESTION: To take home the point to be made about the number of plants operating as so far approved, could I ask Mr. Semerad, since there were so many plants and so few approved so far, what is the implication to a plant's operating without USDA approval?

MR. SEMERAD: The question is that since we have so many plants operating already commercially and only three so far approved, what are the implications with respect to those not yet approved.

Actually, I must explain the operation of our Agricultural Environmental Service inspection. On manufactured parts our inspection is a voluntary thing. We inspect only those plants that ask for it, and so far we have had a handful of requests. We've approved three plants. We expect some additional plants will ask for inspections, and we think the list will grow.

But whereas in this country it's legal to operate without just the inspection, this is only an optional requirement--I mean an optional service that we offer, and so there is really no implications, the market is still open to the companies that are not USDA approved.

WHEY DEHYDRATION PROCESS

T. Silverman

PTX Food Corporation
White Plains, NY

Considerable research and development has been devoted to the application of the Carver Greenfield Process for the dehydration of dairy products, particularly to the drying of whole milk powder and whey products. By reviewing the milk dehydration work, it is possible to understand the evolution of the Process in its application to the dehydration of whey and other dairy products.

The work in milk powder dehydration started in the 1950's when considerable laboratory and pilot plant development work was carried out. In 1964 the process was licensed to the Colgate Palmolive Co. who, working with Producers Creamery Co. at Springfield, MO. (now Mid-America Darymen, Inc.), set up a semiworks plant which had a capability of producing 100 pounds of dried milk per hour. Burdet Heineman, at that time, was in charge of this development work for Producers Creamery.

The quality of the whole milk powder produced was remarkable with exceptionally good solubility (solubility index 0.02), good flavor, and a shelf life of over a year at elevated storage temperatures. In fact, this year we discovered a dozen cans of this whole milk powder in our attic. It was produced in April 1963. Temperatures, in this storage area, exceeded 120°F during the summer months. Some of these cans were opened out of curiosity and much to our surprise the milk was absolutely palatable. There was a slightly oxidized flavor but no more than is sometimes found in normal market milk. The solubility was still excellent. We think that this discovery may have some far-reaching implications in the world programs of storage of dairy product when we think of products beyond the traditionally subsidized butter, cheese, and skim milk.

Incidentally, during the tasting of the rehydrated milk, one of the panel members remarked that it was eerie drinking milk from a cow that had been dead over 10 years.

The product has excellent stability since it had been produced under exceptionally high vacuum and relatively low temperatures. The product particle is highly dense, as compared with spray-dried product, with no entrapped air in the individual particles. The optimum water content in the crystallization phase effects maximum crystallization giving the product excellent instantizing properties. This, coupled with the previously mentioned high density of the particles, makes for excellent wetability, since the finished product will not float on the surface of the water during rehydration.

The basic Carver Greenfield Process brings the product to complete dryness in a multieffect evaporation system without the use of spray, tray, drum, or other conventional drying equipment. This process is illustrated in Figures 1 and 2. As we well know, the multieffect evaporator is one of the most

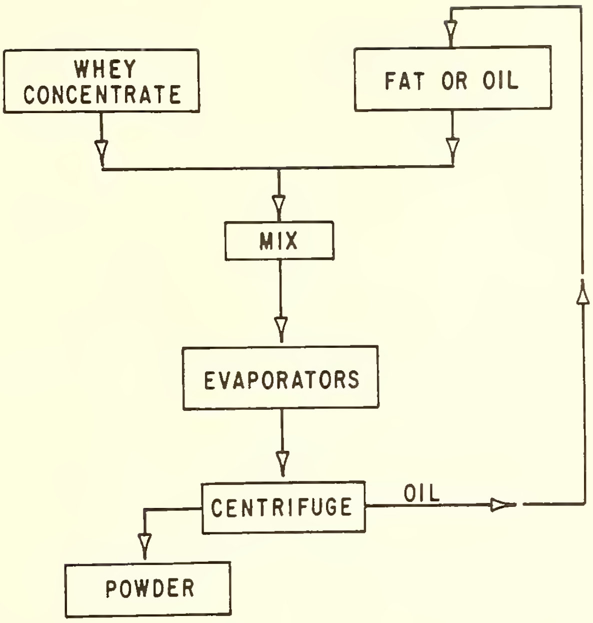


Figure 1

efficient methods known today for the removal of moisture from products. Previously, the limitation of its use depended on the viscosity of the concentrated material. Concentration of product is made to the stage whereby the concentrate must be further dried by the spray or other conventional methods, since a viscous product cannot be circulated through a tube chest.

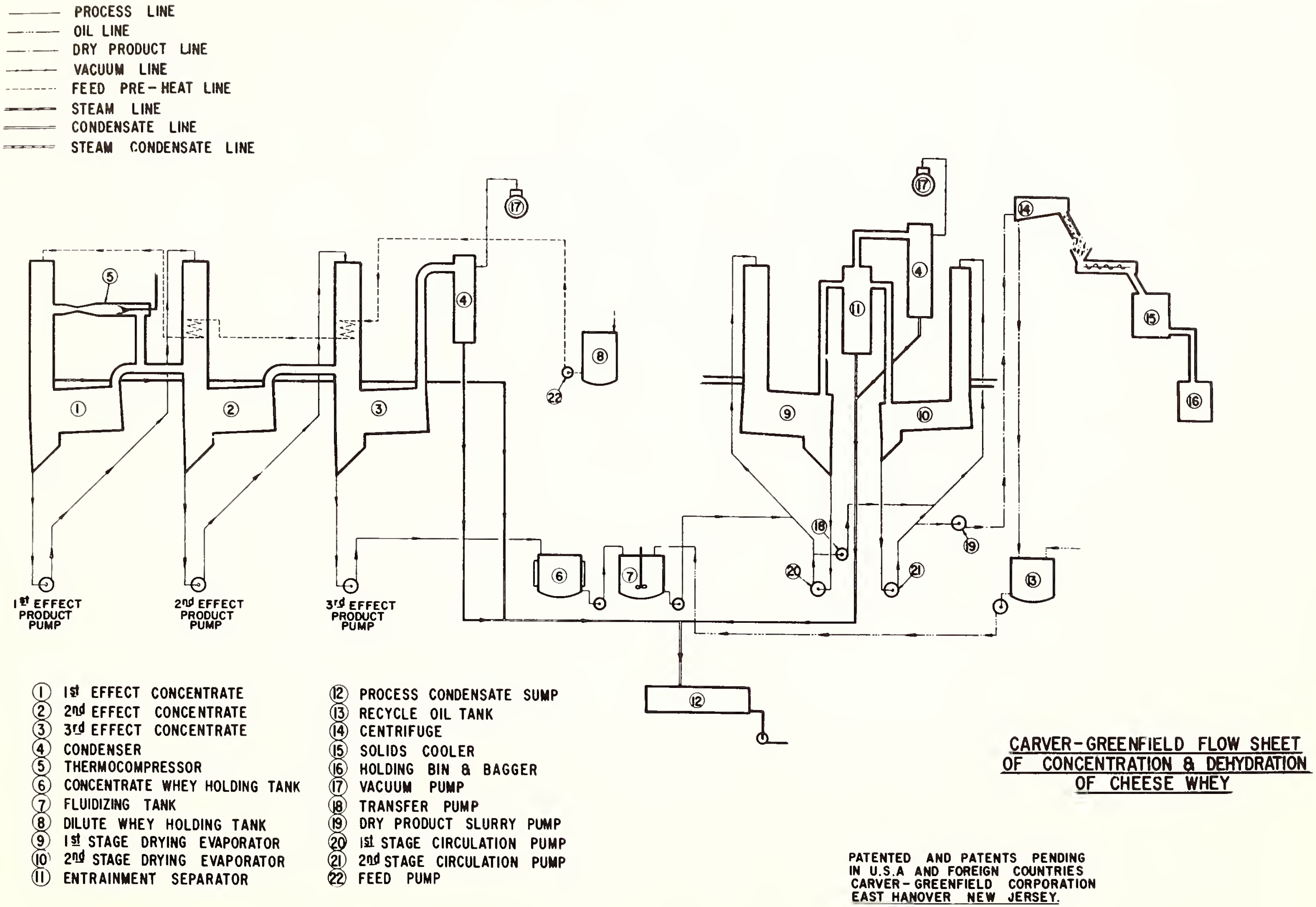
The key to the Carver Greenfield Process is the reduction of the viscosity of the concentrate with an oil or fat, therefore enabling the product to be circulated so that the complete moisture content can be removed in the evaporators.

With the use of approximately 6 to 10 times oil content to the amount of solids (on a dry basis), we effectively accomplish the fluidity of the mixture. The oil is then separated from the dried solids by a centrifuge leaving a free flowing powder. The separated oil is then recycled back to the feed of the evaporators.

In the case of whey, oil or fat is added to the concentrated whey at 35 to 50 percent solids. At drying temperatures of 140°F but no greater than 162°F employed with vacuums of 28.5 to 29 inches mercury, the proteins of the resultant product will be completely undenatured. The final product will contain residual fats between 8 to 35 percent and can be controlled by a number of factors:

1. Particle size of the dehydrated solids.

2. Type of centrifuge.



CARVER-GREENFIELD FLOW SHEET OF CONCENTRATION & DEHYDRATION OF CHEESE WHEY

Figure 4

3. Time/force ratio of the centrifuge.

4. Emulsification system.

5. Temperature of the fat-solid slurry fed to centrifuge.

6. Type of oil or fat used.

7. Protein and carbohydrate content of finished product.

8. Ratio of oil to solids.

The Carver Greenfield Process does not require any special type oils or fats for its operation. In fact, we have used in the various plants constructed and in pilot work, commercial oils ranging from fuel oils to essential oils.

You might note this paper is entitled as a WHEY DEHYDRATION PROCESS. The system is more than a dehydration system and must truly be called a PROCESS. By taking advantage of the physical and chemical characteristics of these oils, we are able to accomplish in-line extractions and chemical changes of products. For example, during the drying of such products as eggs and meat, cholesterol is soluble in the fat phase. By breaking the recycle oil line, between the centrifuge and the return to the evaporators, we have the ability to remove the cholesterol from the oil. Therefore, the finished products can either be a reduced or even cholesterol-free.

We also use this same type of technique to produce fat-free products. This is accomplished by using a specific type oil called Isopar (a product of Exxon). This oil, a carefully fractionated isoparaffinic hydrocarbon of the aviation fuel industry, has unique characteristics. Its boiling range is approximately 350^{o}F although it starts to flash at about 125^{o}F. However, it also acts as a solvent for other fats. By using a suitable evaporation technique, we separate the dissolved fats from the isopar before returning it to the system.

Since the isopar is steam distillable, we remove residuals from the finished product by a technique we call "hydroextraction." By placing the finished product in a "Porcupine" unit, designed by the Bethlehem Corporation, the residual isopar is removed by sparging superheated steam, under vacuum, through the dried material. We are able to reduce the finished products to about 100 ppm of isopar which is well within the FDA limits of products presently approved for edible purposes. Very little energy or isopar is lost since the extracted isopar and steam are returned to the shell side of the evaporator for recycling.

A great deal of pilot work has been completed for an English company contemplating the use of this system for drying and extracting phospholipids from their single cell protein. I would point out that this process is completely safe, especially when compared to other solvent extraction systems such as hexane. There is no need for special pumps, electrical systems or other safety precautions. All our equipment would be the normal type that would be used in dairy and other food type operations.

There are a number of advantages and relatively few disadvantages to the Carver Greenfield Process. Some of these advantages are:

1. Two thirds the investment compared to spray drying.
2. Over 40 percent operational savings as compared with spray drying.
3. No limit to the viscosity of the product to be dried.
4. No necessary pH adjustment to product to be dried.
5. Production of nonhygroscopic product.
6. No dusting problems due to encapsulated particles.
7. Higher density product (lower warehousing and package cost).
8. Instantized type product without secondary treatment.
9. No wetting or foaming problems on rehydration.
10. No bacterial problems such as Salmonella.
11. No air pollution problem (no fines in air).
12. No product loss such as cyclone or wet scrubber waste.
13. Practical for small or large operations compared spray driers.
14. No burn on since system fat-coated.
15. Long runs practical without scorched particles.
16. Less cleanup.
17. Ability to alter chemical and functional characteristics during process.

Some disadvantages would be:

1. Product with residual fat.
2. Product too dense for bulking agent.

Since the Carver Greenfield Process has no particular preference for the type of oil or fat used, the operator must be more selective in his choice of oils for his finished product. As people involved in the food industry, I think you would be hard put to name more than two or three products, other than soft drinks, that are not ultimately combined with some fat in its final use. In fact, premiums are usually paid to the producers of dehydrated products that are combined with fats and oils. Therefore, this disadvantage can really be turned to an advantage in the normal dehydration of the final product. For example, if whey is to be used as a calf milk replacer then lard or tallow should be used as the fat carrier. If destined for the baking industry then a shortening should be used. If for the confectionery or chocolate industry, then butterfat, coca fats, hard butters, or combinations of these fats should be used.

The versatility and application of the Carver Greenfield Process is limited only by the imagination and resourcefulness of the operator. If we revue some of the past work, perhaps this can best be illustrated.

We are well aware of the viscosity problems that are associated with the production of soy flour, starch, and other mixtures with whey. As previously mentioned, viscosity problems do not exist with the Carver Greenfield Process. In fact, the economics are even more attractive in these areas. However, let us go one step further. We find that pregelatinizing, solubilizing, and modifying starches in oil is both economic and practical. This can be accomplished during the course of drying.

For the chocolate industry, products with low moisture are highly desirable. With the Carver Greenfield Process we can, if necessary, obtain products that are even anhydrous. In addition, we can control the particle size of the finished product. Thus, we can produce products that are combinations of sugar, coca butter, and other dairy fractions not only having low moisture and small particle size but also with the fat in a free state. This, of course, makes the finished product ideal for this industry. In fact, some of our work shows that conching time for the chocolate can be drastically reduced.

For the production of acid whey, dried for the baking industry, particles can be encapsulated which can be most desirable for control in the chemical leavening of such products as pancakes and sour cream chocolate cake.

As previously mentioned, the capital costs of the system are about one-third less than a comparable spray drying system. However, the energy saving phase is even more important. We are well aware that a spray drier consumes about 2.5 to 3 pounds of steam for 1 pound of water evaporation. Now consider a triple effect evaporator using 1 pound of steam to evaporate 3 pounds of water. We can readily see why the Carver Greenfield Process must be considered as having a vast impact in an industry dehydrating whey containing over 93 percent water. In fact, as the cost of energy rises the impact of energy saving will gain an even further economic advantage.

Table I shows a comparison of Carver Greenfield Dehydration with spray drying. This comparison is made starting from 6.5 percent solids.

During the 1960's, the Carver Greenfield Process was applied to the inedible fat rendering industry as well as to many applications of industrial and municipal wastes. There are now nearly 100 plants in operation around the world processing these materials.

However, the food field was not completely neglected. Much work has been in pilot operations of such food products as yeast and other single cell proteins, dairy products such as dehydrated cheeses, hydralyzed lactose, dried

TABLE I.--Comparison of Carver Greenfield (CG) and and spray drying process

Cost per day of 23,630 lb product (2,000 to 3,000 lb per hour)

Item	CG process	Spray drying
	Dollars	Dollars
Equipment amortized 10 year at 12% interest (260 days per year)	430.77	558.65
Building amortized 20 year at 10% interest (260 days per year)	51.92	144.23
Steam @ $3.00/1,000 lb	356.00	531.00
Electric @ $0.03/KWH	56.99	84.96
Labor @ $5.00/hr (operator and baggers)	116.25	116.25
Repair and maintenance	10.76	13.97
Insurance and taxes	14.49	21.09
Bags (packaging)	94.52	189.04
Cost per day	1,131.70	1,659.19
Cost per pound	0.0479[1]	0.0702[2]

[1] There would be an additional 1 to 2 percent savings of product loss due to the problems of cyclones and wet scrubbers which are lost in spray drying operations.

[2] If operated in two shifts, there will be a reduction of about $0.01 per pound in depreciation.

A total cost of under 4 cents per pound can normally be achieved with whey drying by the Carver Greenfield Process on units of one ton per hour or larger.

yoghurt (with the organisms still viable), vegetables, soy isolates, concentrates and soy whey, fruits, eggs, edible meat, and bone proteins as well as many other food items.

Our first dairy plant was commissioned in Germany in the early part of 1976 and our second dairy plant is expected to start the latter part of 1976 in the United States. Although these plants were designed to process whey, both operations have a planned program for development of a sophisticated line of dairy and whey based products that will be produced at great economic advantage.

QUESTION: I would like to ask Mr. Silverman if he is free to disclose what types of oils are being used in the plant put together in Germany and that are coming on stream, the one plant coming on stream in the United States.

MR. SILVERMAN: We have been using a variety of oils, oils that are naturally used for milling requirements, which are not only lard and tallow and vegetable oils, we have been using some soy oils, and I suppose eventually, although I'm not sure if they answer the entire problem they will be using butter oils in their system. But we use a complete range, and as mentioned before, the oil really is not much of a difference, makes no difference for what is used in the system.

UTILIZATION OF WHEY AS A HUMAN FOOD

K. M. SHAHANI

University of Nebraska
Lincoln, NE 68583

Annual whey production in the world is estimated to be 74 million tons or 162.8 billion pounds, 95 percent of which is cheese whey (10). The remaining 5 percent results from the manufacture of casein and heat or acid coagulated milk products in various parts of the world. In the United States, approximately 30.5 billion pounds of cheese whey or 1.983 billion pounds of whey solids were produced in 1974. Of this, about 56 percent of the whey solids are currently utilized in human and animal feeds and the rest is wasted (7). The various forms of cheese whey utilized in human foods in 1975 are listed in Table I.

TABLE I.--U.S. production of whey products for human use, 1975

Product	Million pound
Dried whey	411.8
Condensed whey	88.3
Partially delactosed whey	24.5
Partially demineralized whey	21.9
Partially delactosed/demineralized whey	4.5

Source: U.S. Statistical Reporting Service.

Current trends indicate a steady increase in the availability of whey in the future and newer technologies need to be developed to enhance whey solids utilization for human consumption. Traditionally, whey has not been considered to be a highly rich source of nutrients for humans because of its low protein content and high mineral and lactose levels. However, in recent years efforts have been intensified to utilize all the constituents in whey in a composite manner. The nutritional and physiological functions of whey proteins and lactose have been delineated by several workers (1, 4, 8). A variety of new uses for whey has been suggested including its use in the production of cheese (such as Ricotta) and related products, whey protein concentrates (WPC), infant food formulations, special dietary products, soup, and gravy bases, cheese culture medium, and beverages. Some of these developments will be discussed in this paper.

Production of Cheese and Related Foods

It has been suggested that whey or whey protein concentrates and hydrolysates can be used in the manufacture of cheese, processed cheese, and related foods. As early as 1946, Webb and Hufnagel (9) reported that heat denatured whey proteins, obtained by heating whey to 92°C for 15 min in the presence of 0.5 percent $CaCl_2$, could be satisfactorily blended with processed cheese foods. Ricotta, a soft unripened variety of Italian cheese, is gaining popularity in the United States where this cheese is manufactured from whole milk in contrast to the Italian practice of using whey-milk blends. In such blends used in Italy, the ratios of whey:milk vary from 90:10 to 97:3 and heating the blends causes protein coagulation, the resultant product being Ricotta cheese. Employing this method, however, only about 50 percent of the proteins can be recovered. Experiments conducted in our laboratory have been concerned with improving the recovery of proteins from such systems. A whey-whole milk blend, when heated in the presence of 500 or 1,000 ppm calcium (supplied as $CaCl_2$) resulted in better yields than the conventional process (Table II). Further, this process was adaptable to whey obtained from Cheddar, Husker, Mozzarella, or Swiss cheese manufacture. Although Ricotta made with whey:skim milk blends had a higher protein content than Ricotta made from whey:whole milk blends (Table III), the latter appeared to yield a soft, more typical and higher quality Ricotta.

TABLE II.--Effect of addition of calcium on the recovery of proteins by heat from different whey:milk blends[1]

Whey:milk system	Recovery of proteins		
	Heat	Heat + 500 ppm Ca	Heat + 2,000 ppm Ca
	Percent		
Cheddar whey	48.2	65.4	77.8
Swiss cheese whey	53.0	63.7	78.3
Mozzarella whey	48.9	65.3	72.4
Husker cheese whey	45.4	66.1	74.1

[1] Whey:milk blends contained 95 parts whey and 5 parts milk.

Apart from making Ricotta cheese, Devos and coworkers (3) developed and patented a method of improving characteristics of cheese by the addition of whey proteins. Also, it has been reported that the addition of whey protein hydrolysates or casein accelerated the ripening process of pickled cheese (6). On the other hand, however, the addition of whey proteins to cheese has been shown to increase the bound water and lactose contents of the curd, which, in turn, leads to increased acidity, and inferior flavor, body, and texture. Cheese prepared from milk fortified with whey proteins has been shown to be rheologically inferior. The values for hardness and firmness, modules of elasticity, viscosity, and relaxation times were significantly lower than the corresponding values for normal cheese. Based upon the above information, it

TABLE III.--Composition of Ricotta prepared from "whey-milk" blends employing heat/acid for coagulation of proteins

Constituent	WPC from whey-skim milk system	WPC whey-whole milk system
	Percent	
Proteins	63.99	53.76
Fat	12.60	27.52
Lactose	21.31	17.46
Ash	2.10	1.90

is felt that although the incorporation of whey or whey protein concentrates in cheese and cheese foods appears to be a viable alternative, considerably more research work needs to be done to standardize the techniques.

Manufacture of Whey-Protein Concentrates (WPC)

In recent years the geometric increase in world population and the arithmetic increase in food production has created the problem of protein-calorie malnutrition. Various vegetable protein sources are being tested for their efficacy to overcome dietary protein shortages. Vegetable proteins lack one or more essential amino acids and this is deleterious to protein utilization in vivo. Whey proteins, on the other hand, have adequate levels of essential amino acids and are easily digestible, and are thus considered to be highly nutritional and physiologically complete. In addition, they have excellent functional characteristics.

Attempts have been concentrated on isolating these proteins without sacrificing their desirable properties. In our laboratory, whey proteins have been isolated by using carboxymethylcellulose, ferric chloride, ferripolyphosphates, polyacrylic acid, and sodium hexametaphosphate, and data concerning their relative efficacy are presented in Table IV. These polyelectrolytes bind proteins in whey via the electrostatic interaction and produce a flocculent precipitate at their isoelectric point. Since this "cold precipitation" technique recovers the whey proteins in their native form, they retain most of their functional characteristics and are thus considered superior to those recovered by the "heat-coagulation" process. However, cold precipitation generally results in WPC with a high mineral content varying from 12.8 to 28.4 percent which can cause numerous processing or nutritional problems. Nevertheless, the mineral content can be reduced significantly by a combination of chemical treatment and gel filtration (Figure 1). In the case of WPC obtained by SHMP, the high phosphorus content can be reduced by treating with $Ca(OH)_2$ at pH 9.0 and filtration through a Sephadex G-10 or G-25 bed. The reduction in mineral content through such treatments has been shown in Table V. The resulting products were high in protein, low in minerals, and retained

TABLE IV.--Recovery and composition of whey protein concentrate (WPC) by cold precipitation technique

Polyelectrolyte used	Recovery of proteins	Composition of WPC Protein	Composition of WPC Ash
	Percent		
Ferric chloride	88.7	79.1	18.3
Ferripolyphosphate	91.7	69.5	28.4
Polyacrylic acid	63.3	82.0	12.9
Sodium hexametaphosphate	75.5	84.9	12.8

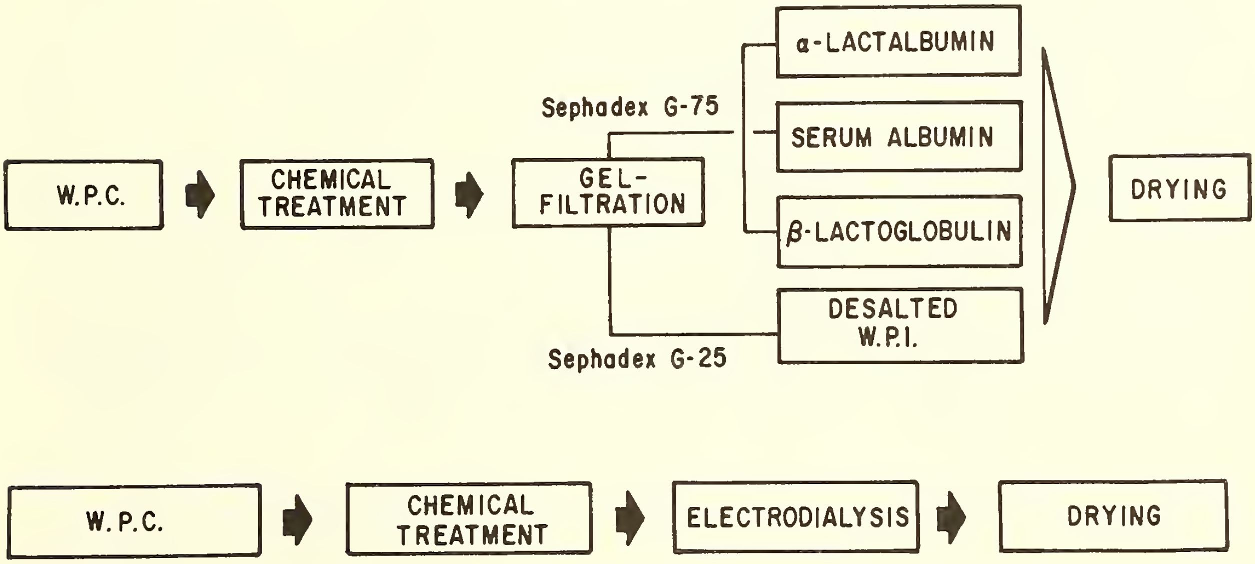


Figure 1.--Suggested techniques for reducing ash content of whey protein concentrates.

excellent solubility characteristics. WPC has also been prepared commercially using ultrafiltration, reverse osmosis, and electrodialysis. Morr (7) and Delaney (2) have reviewed the properties of such products. The general desirable characteristics of WPC isolated by this technique are solubility, viscosity, stabilizing and emulsifying capacities, foaming, gelation, and water sorption. Thus, WPC can be used in milk replacers, egg substitutes, ice cream mixes, processed cheese foods, whipped toppings, and the like.

TABLE V.--Mineral content of WPC before and after chemical treatment and desalting on Sephadex G-25

Type of WPC	Original mineral content Percent	Mineral content of refined WPC Percent
$FeCl_3$ - WPC	18.3	1.4
FPP - WPC	28.4	4.7
SHMP	12.8	1.1

Manufacture of Infant Foods

Infant nutriture places certain special demands on the formulation of baby foods. Recent reports have indicated that some infants fed exclusively on cow's milk suffer from physiological disorders such as microcytosis, ferropenia, and minimal anemia. These disorders are believed to arise from impaired organ functions in the infants and can be rectified by feeding diets more closely resembling human milk. The process of preparing infant food formulae resembling human milk is popularly referred to as the "humanization" of milk. Certain compositional differences exist between human and bovine milk. For example, human milk has a higher level of lactose and a greater percentage of the proteins are whey proteins. In the "humanization" of bovine milk, these differences in composition are minimized by the addition of lactose and whey proteins. Another solution to this problem has been to use WPC or demineralized whey as the base and to add the required amounts of casein and fatty acids to simulate human milk.

A scheme for the isolation of alpha-lactalbumin, serum albumin, and lactoferrin fractions from WPC and their subsequent use in formulations of infant foods is illustrated in Figures 2 and 3. The feeding of "humanized" milks exert considerably low osmolar loads and increase nitrogen retention and utilization. Since good quality protein is an essential ingredient for the development of infants, whey or whey proteins can be used to extend current milk supplies in developing countries thereby contributing to the abatement of protein-calorie malnutrition. It has been estimated that the manufacture of humanized milk powder, using whey, would cost approximately 66 cents per pound, which is exceedingly competitive in price with several infant foods currently on the market.

Manufacture of Specialized Diets

Just as the normal infant nutrition places specialized demands on baby foods, invalids, geriatrics, and infants suffering from cardiac malfunction require certain specialized diets. Convalescent patients under post-operative care who may suffer from impaired digestive functions require special diets,

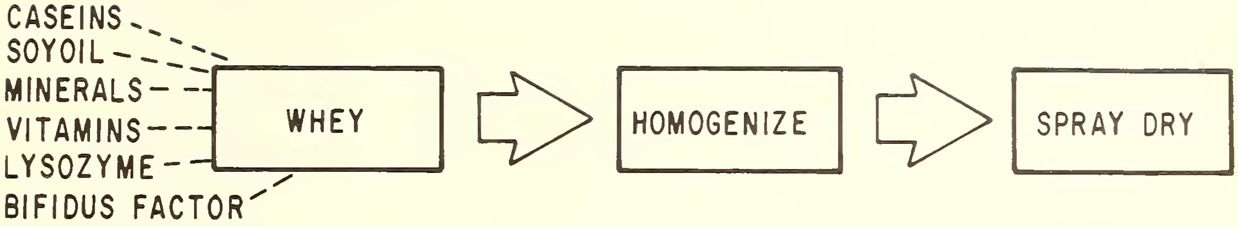


Figure 2.--New approach suggested for the formulation of humanized milk food using whey as base.

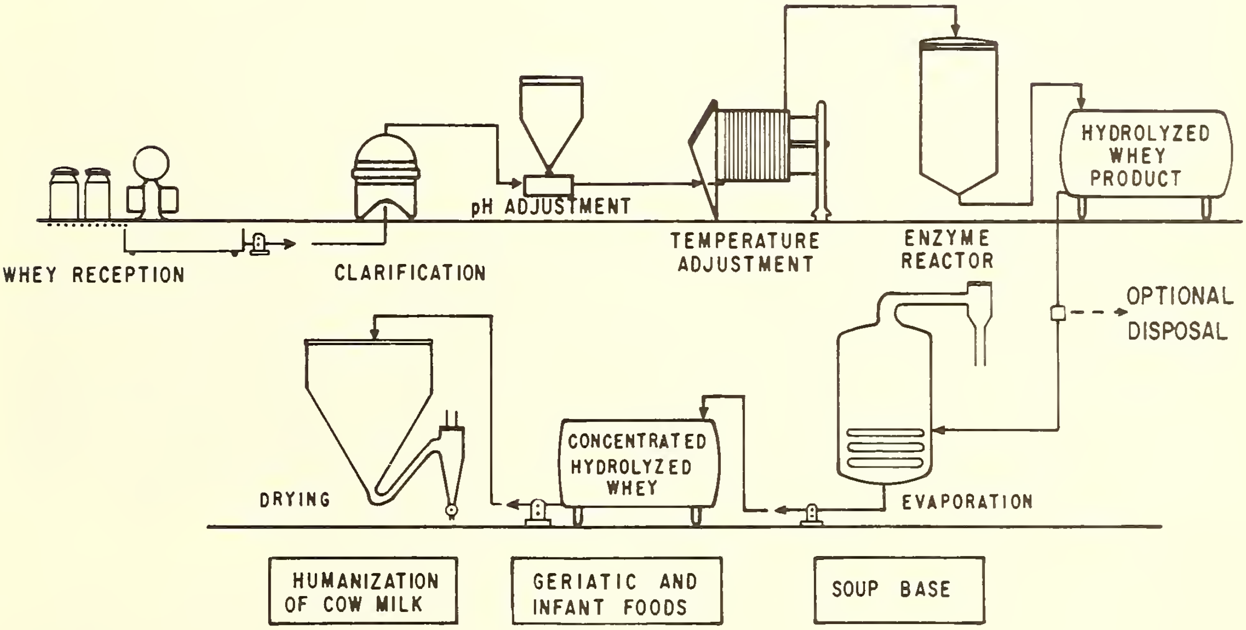


Figure 3.--Conceptual design of a system to process and utilize whey.

low in residue and high in caloric density. This is another area in which whey or whey concentrates can play an important role. A collaborative effort between our group and pediatricians at the University of Nebraska Medical Center at Omaha has been working on the development of a whey-based infant formula for cardiac infants (Table VI). Electrodialyzed whey is used as a source of proteins and carbohydrates. Additional caloric supplementation is achieved by the addition of gluco-oligosaccharides and medium chain triglycerides.

TABLE VI.--Formulation of special diets

Contents	Precision LR diet	Our formulation
Ingredients	Maltodextrins, pasteurized egg white solids, sugar, calcium glycerophosphate, potassium bitartrate, magnesium sulfate, vegetable oil, citric acid, natural and artificial flavor, vitamins and minerals	Maltodextrins, vegetable oil, whey protein concentrate, soy protein isolate, vitamins, artificial flavor and color
Composition:		
Protein	8.8 percent	8.3 percent
Carbohydrate	84.0 percent	63.3 percent
Fat	0.3 percent	28.4 percent
Calories	1900/510 g (18 oz)	2528/510 g (18 oz)

Another suggested approach to providing convalescing patients with adequate nutrients is to hydrolyze the proteins and lactose in whey by enzymatic means and then incorporate the hydrolyzed whey into products. The idea here is that perhaps hydrolyzed products will lead to a quicker absorption of nutrients. Although the overall quantity of whey used in these products will be low in comparison to the total whey available, it is an economically viable method of using whey in human nutrition. Specialized formulated diets such as these are expensive by nature and the costs incurred in removing minerals from whey or hydrolyzing the constituents are not considered to be too great.

Manufacture of Soup and Gravy Mixes

Utilization of whey for producing soup and gravy bases is a very promising area. A wide variety of seasonings can be used to produce varying flavors. In our laboratory we have formulated a soup base which has the potential for being used in a wide variety of soups. A French onion soup prepared with this base was subjected to cost accounting and its cost is only 1 cent per 8 oz cup, including the cost of ingredients, processing and overhead, but not packaging. The product still under development has desirable organoleptic characteristics. Furthermore, the same dry soup base can be profitably used as a gravy base for numerous dishes.

The estimated cost of manufacturing "soup base" is as follows:

$$C_M = C_R + C_D + C_I + C_F$$

C_M = Cost of manufacture

C_R = Cost of raw materials

C_D = Direct costs = $0.25\ C_R$

C_I = Indirect costs = $0.10\ C_R$

C_F = Fixed cost = $0.05\ C_R$

$$C_M = 163.6530 + 40.9132 + 16.3653 + 8.1826 = \$229.1142/1{,}000\ \text{lb}$$

Number of 8 oz cups from 1,000 lb of dried product

(Reconstituted to 10 percent solids) = 20,000

Estimated cost of soup base/cup = $0.0115/cup

Manufacture of Culture Media

The cultured dairy products, such as yogurt, sour cream, cheeses, and buttermilk, require the addition of starter culture to milk. The starter organisms are generally grown as milk cultures. However, media made with whey as a base can also be successfully used to grow these microorganisms. A medium formulated at the University of Nebraska using whey as the major component is capable of propagating cultures used in Cottage, Cheddar, and Swiss cheese manufacture as well as the yogurt culture. The cost of such a medium is lower than that of nonfat dry milk or other commercial media currently available (Figure 4). Skim milk powder costs 65 cents per pound and when reconstituted supports the growth of 2 billion organisms/ml. Whey-based media, on the other hand, costs 22 cents per pound and can support 38 billion organisms/ml. The advantages are obvious; a product costing one-third as much as skim milk can support a microbial population 19 times greater than that of skim milk. This process will provide for a reuse of significant quantities of cheese whey generated in a cheese plant.

Manufacture of Beverages

The therapeutic administration of whey can be traced back to Hippocrates (460 B.C.) who prescribed this fluid for an assortment of human ailments. However, in modern times whey beverages are not considered to be a panacea and are consumed solely for pleasure. Research dealing with whey beverages has been extensively reviewed by Holsinger and others (5). Generally, there are three catagories of beverages: (1) alcoholic, (2) nonalcoholic, and (3) high protein beverages. Alcoholic beverages are prepared from deproteinized whey such as the sparkling champagnelike whey beverage "lactovit" produced in Poland. The annual consumption of this beverage in Poland amounts to about

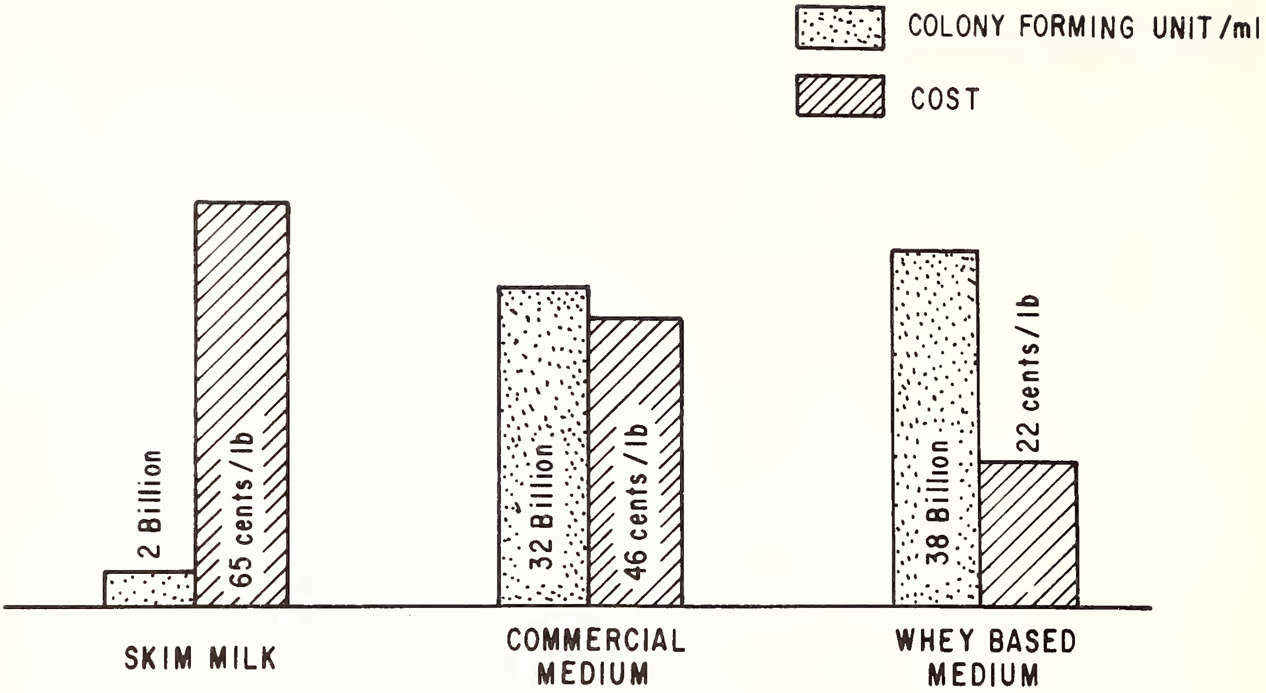


Figure 4.--Bacterial growth and cost of different culture mediums.

230,000 liters. During World War II in Germany, a general shortage of raw materials led to the use of whey in producing a beerlike drink. Additionally, a number of methods have been patented to prepare winelike products containing up to 10 percent alcohol using whey as the substrate. Nonalcoholic beverages are generally mixed with fruit juices and provide a nutritious alternative to carbonated soft drinks. In western Europe a whey beverage called Rivella has enjoyed some popularity and is currently being test marketed in this country. Protein beverages were developed to combat malnutrition by marketing proteins in an attractive palatable manner. In such products WPC and WPC-soy protein blends have been used with limited success.

Conclusions

This paper has attempted to put into perspective the methods of utilizing whey for human consumption. With the advancement of science and technology, many processes that may not be commercially feasible today will be transformed to practical success in the future. Efforts, thus far, have been to selectively utilize components of the whey; for example, the whey proteins. WPC can be successfully used in a variety of products, but the process of producing WPC results in lactose as a byproduct. Applications for lactose in food formulations are limited due to the physico-chemical properties of this disaccharide. If lactose is allowed to be wasted, then a valuable source of nutrient would be lost and the problem of whey utilization will still persist. It would be more desirable to concentrate our efforts on finding newer methods of utilizing a majority of the whey rather than resorting to selective fractionation methods. Only total utilization of all whey constituents can lead to the successful solution of the problem that we face today.

LITERATURE CITED

(1) Babad, H., and Hassid, Z. 1962. Soluble uridine diphosphate D-galactose: D-glucose β 4-1, galactosyltransferase from bovine milk. J. Biol. Chem. 24: 2672.

(2) Delaney, R. A. M. 1976. Composition, properties and uses of whey protein concentrates. J. Soc. Dairy Technol. 20: 91.

(3) Devos, P., Desjonqueres, A., and Rambaud, M. 1960. French Pat. 1,237,225.

(4) Forsum, E. 1974. Nutritional evaluation of whey protein concentrates and their fractions. J. Dairy Sci. 57: 665.

(5) Holsinger, V. H., Posati, L. P., and DeVilbiss, E. D. 1974. Whey beverages: A review. J. Dairy Sci. 57: 849.

(6) Mel'Nike, E. 1963. Accelerating the ripening of pickled cheese. Mol. Prom. 24: 227.

(7) Morr, C. V. 1976. Whey protein concentrates: an update. Food Technol. 14: 18.

(8) Webb, B. H., and Johnson, A. H. 1965. Fundamentals of Dairy Chemistry. AVI Publishing Co. Inc., Westport, Conn.

(9) Webb, B. H., and Hufnagel, C. F. 1946. The manufacture and use of condensed whey and crude whey proteins. Natl. Butter Cheese J. 37: 34.

(10) de Witt, J. N., and de Boer, R. 1975. Ultrafiltration of cheese whey and some functional properties of resulting whey protein concentrate. Nathr. Milk Dairy J. 29: 198.

UTILIZING WHEY AS AN ANIMAL FEEDSTUFF

F. W. JUENGST, JR.

Calor Agriculture Research
Okemos, MI 48864

Whey contains an excellent array of high quality nutrients, such as albumen, lactose, vitamins, and minerals, however, so do many other commonly used foodstuffs. Consequently, in its utilization as an animal feed, whey is not necessarily the product of choice for supplying energy and nutrients. Because of this, whey in the view of many is and probably will continue to be a price follower and not a price leader. The volume of whey produced, coupled with good supplies of competing commodities as corn and soybeans, will continue to act as a constraint on whey product prices in the animal feed area.

The need to develop new uses of whey or methods to improve its usefulness for specific applications is apparent to most of us as is clearly evidenced by the research effort across a wide area. I will (1) discuss uses of whey for animal feeds and some of the problems that limit its use in this area, (2) describe in somewhat more detail an approach that utilizes the inherent qualities of whey (lactose, albumen, vitamins, and minerals), and (3) discuss whey's potential in this specific instance. In 1976 Schingoethe (15) published an excellent review of whey utilization in animal feeding.

The major share of whey used in animal feeds is for the ruminant. These animals have no problem with lactose and rather large quantities of whey can be fed. Whey can and is being fed to monogastric animals, such as the pig, chicken, dog, and cat. The total volume of whey used for these purposes is rather limited because in varying degrees, lactose intolerance problems restrict the level of whey solids which can be incorporated into these feeds.

Swine feeds formulated with low levels of dry whey powder represent an important use of dry whey in animal feeds. The formulation of pre- and post-weaning diets can and do utilize high levels of dry whey powder. The baby pig can tolerate high levels of lactose in his diet up to weaning age which is about 6 to 8 weeks. Aside from the standard nutritional qualities of whey powder, whey has additional value as a sweetner in baby pig starter diets and encourages the pig to start eating dry feeds at an early age. At this stage (8 weeks) the level of dry whey powder in the pig's diet has to be reduced below 20 percent of dry matter because of the adult pig's growing intolerance to lactose. However, subject to this upper limit, how much whey is incorporated into the feed depends entirely on the price and quality of alternate sources of protein, vitamins, minerals, and energy.

Poultry feeds utilize very small quantities of dry whey powder since these birds are devoid of the lactase enzyme necessary to utilize lactose. This problem is recognized by poultry nutritionists and feed formulators. They generally agree that regardless of the price of dry whey powder, the concentration should never exceed more than 7 percent of the dry matter intake in broiler and layer hens' diets and the optimal level is around 3 to 4 percent in this application. Whey is reported to increase weight gains, aid digestibility, and supply B vitamins. Because the dog, cat, pigs, and chickens are similar, very large quantities of whey regardless of price will probably never be used in their feed. Methods for converting lactose to glucose and galactose are available but other processes are more economical and therefore, such conversion would add to the cost of whey disposal.

Beef and dairy cattle can consume large quantities of whey. As stated earlier, most of the feed grade whey enters the ruminant market. One large use is as a milk replacer feed for calves. Schingoethe (15) pointed out that there is little agreement on how much milk can be replaced with whey. Some studies showed that 45 to 60 percent replacement impairs animal performance while other studies go as high as 89 percent replacement with no reduction in calf growth rates. Other factors such as replacer formulation or animal genetics may play some role.

Beef and dairy cattle readily consume liquid whey from 132 to 410 pounds per day (15). However, at high intake rates excessive urination occurs and if the whey becomes too acid, these animals may reject the whey. Transportation costs for liquid whey also place a major limitation on its use in this form.

Cattle will consume condensed whey or dry whey when mixed with feeds or silage but a major limitation is whey's economic value as a source of protein, energy, and minerals particularly as these nutrients can be obtained from numerous other sources.

Two years ago (1974) Mr. Boyd of the American Feed Manufacturers Association, spoke to us about whey in animal feeds. His take-home message for us was summarized in the following quotation from his lecture (3).

> "Basically, our feed industry is providing a corn-soy type of diet for animals. The question is, can the product you offer us compete on a nutrient basis, and on a cost basis, with what we already have available? If you are going to supply us with a product that is basically energy in its nature, how will it compete with corn? If it is basically a protein source, how will it compete with soy?"

A comparison of whey with these two competing nutrients--corn and soybean oilmeal (SBM)--is shown in Table I. Whey contains 90 percent of the energy of corn and about 1.6 times more protein. In comparison with SBM, however, dry whey has 30 percent of the protein content and about the same energy value. Thus, whey is comparable to corn but has much less protein than soybean oil meal.

The cost data in Table I illustrates an inescapable problem of feeding whey to ruminants--the cost of whey is comparable to the cost of corn on a dry matter basis. Since these other nutrients are relatively abundant and are expected to be for the foreseeable future, their prices should not increase dramatically, thus the price for whey necessarily will remain low and follow the price of corn. The cost of producing dry whey on the other hand can be expected to increase as fuel becomes scarcer and costs increase.

TABLE I.--Comparison of energy, protein and dry-matter content of whey, soy, and corn

Item	Dry Whey	Soybean meal	Shelled corn
Metabolizable energy..Kcal	2,973	2,851	3,394
Crude protein.........Percent	13.8	45.8	8.90
Dry matter............Percent	94.0	89.0	89.0
Average price/cwt, 1975	5.40	6.25	5.39

One method to increase the value of whey is to elevate its crude protein content to that approaching soybean oilmeal by the addition of nonprotein nitrogen (NPN). NPN can be used by rumen microorganisms to produce microbial protein. The microbial protein is then digested in the acid stomach (abomasum) and utilized by the animal as it would use any other protein. Two excellent sources of NPN are ammonia and urea.

Czarnetzky in 1954 (4) developed one of the early methods of increasing the crude protein (CP) content of whey. Basically, he developed a method to ferment the lactose in whey to lactic acid using lactic acid bacteria, and by adding ammonia gas to control pH, he converted the lactic acid to ammonium lactate. Arnott and coworkers in 1958 (2) described a slightly modified method for ammonium lactate production from whey. These workers fed this material to sheep but experienced some palatability problems (5). Since that time, others have produced a fermented ammoniated condensed whey (FACW) using similar methodology (1, 13) and fed this whey to ruminant animals with no such problems (7, 8, 9, 10, 11, 12).

More recently, Michigan State University researchers worked upon fermentation procedures for the production of FACW and have applied for patents covering their processes (14).

Calor Agriculture Research has concentrated its efforts on the development of a commercial process for producing FACW. A basic scheme for production is shown in Figure 1. The process is applicable to acid or sweet whey. The whey is first transported from the dairies to a fermentation plant; second, the whey is fermented by a normal homolactic fermentation using ammonia to maintain the pH. After fermentation, the whey is subjected to evaporation which increases the solids from 60 to 70 percent with a CP level of 45 to 50 percent.

Our final product is called Bactolac and its characteristics are shown in Table II. This material is free of viable coliforms, fecal streptocci, yeast and molds. Because of its high ammonium lactate content and osmolality, Bactolac's keeping properties are excellent. It is qualitatively and quantitatively stable between 0^{o} to 110^{o}F for at least 6 months.

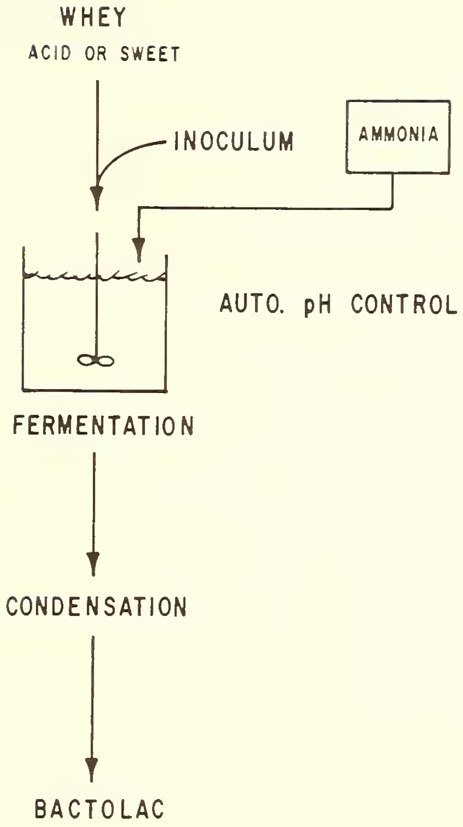


Figure 1.--Scheme for production of bactolac.

Fermentation has effectively added value to the whey because:

1. Bactolac has a CP value equivalent to soybean oilmeal. The major difference between Bactolac and soybean oilmeal in feeding terms, is that Bactolac contains about 80 percent of its CP as NPN.

2. Bactolac contains substantially all of the energy present in the original lactose because very little chemical decomposition occurs during fermentation. Consequently, Bactolac and SBM are similar in total calories on a dry-matter basis.

3. Cost of evaporation is considerably lower than spray drying. Since evaporation of water from whey constitutes the major cost of producing dry whey for animal feeds, the reduced evaporation costs alone place Bactolac at a competitive advantage to dry whey powder.

TABLE II.--Typical analysis of Bactolac 45

Typical analysis	Composition (w/w)
	Percent
Total crude protein (N x 6.25)	45.00
Total nitrogen	7.20
Protein nitrogen	1.22
Nonprotein nitrogen	5.98
Total lactic acid (present as ammonium lactate)	40.00
Total ash	6.00
Calcium	.80
Phosphorus	.70
Total solids	62.00
Total water	38.00
pH	6.80

Bactolac, however, is not just concentrated whey. It is a product with caloric and crude protein values comparable with soybean oilmeal. Consequently, in market terms, it does not compete with dry or concentrated whey but with soybean oilmeal. Therefore, a higher selling price for whey in the form of Bactolac over dry or condensed whey can be reasonably expected on the basis of its feed ingredient value.

4. Pollution problems from a Bactolac plant are minimal since no mother-liquor is left over for disposal. Most other processes for drying and condensing whey also generate condensed water similarly.

5. The process can be applied to deproteinized whey and, therefore, could be added to plants removing protein from whey by ultrafiltration or by resin-exchange methods provided these methods do not remove the low molecular weight compounds (including lactose) and do not add toxic or inhibitory compounds to the whey during deproteinization.

The claim that Bactolac is equivalent to SBM on energy and CP basis and its effectiveness as a crude protein supplement has been established. A number of studies feeding Bactolac to beef and dairy cattly have been completed and portions of two such studies illustrating the efficacy of this material are presented in Figures 2 and 3.

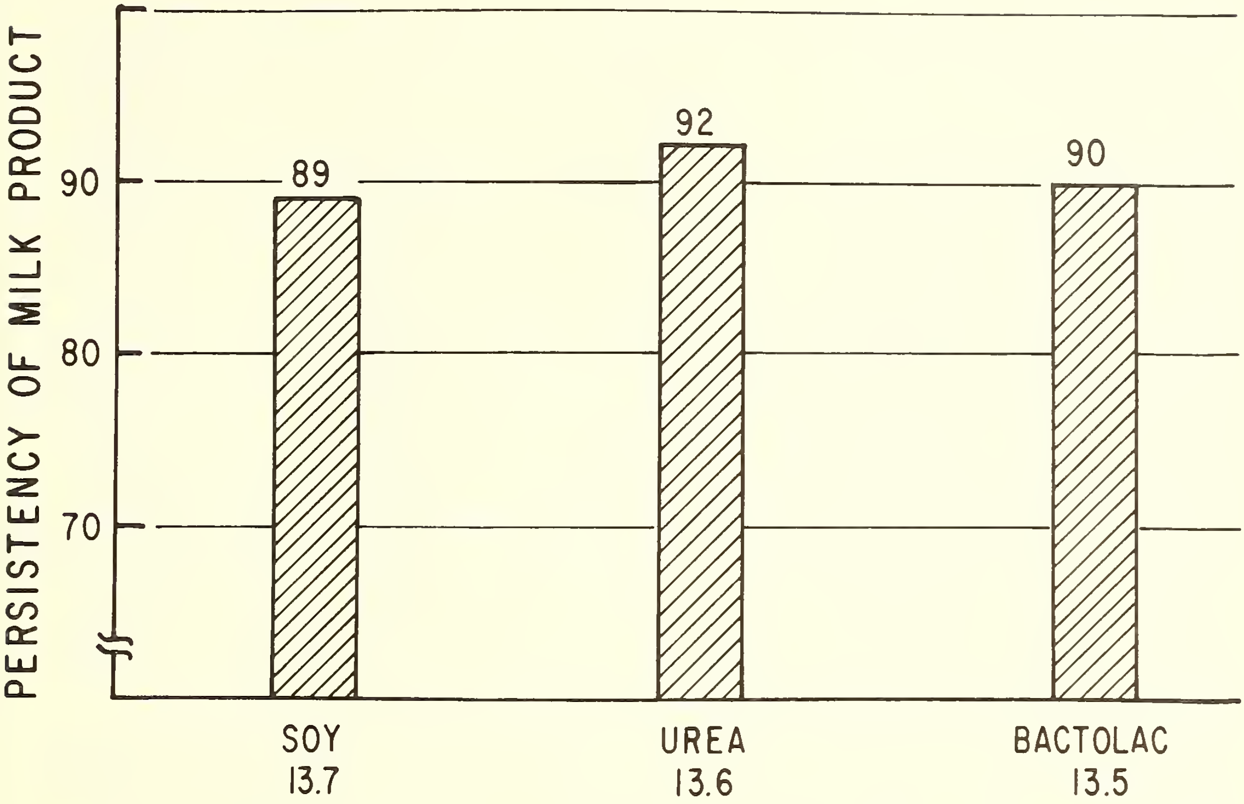


Figure 2.--Effect of isonitrogenous level of soybean oilmeal, urea, and Bactolac on average daily gain of yearling steers (6).

Figure 2 shows the effect of feeding isonitrogenous levels of Bactolac, urea, and SBM to beef cattle. This study was conducted by Henderson and coworkers (6) at Michigan State University. Sixteen yearling steers were used per treatment and the basal ration consisted of 40 percent shelled corn and 60 percent corn silage. The control group received only the basal ration and gained 2.57 pounds per day, which was significantly lower than the nitrogen enriched groups. The urea supplemented group gained 2.84 pounds per day, which turns out to be significantly lower than the Bactolac and SBM fed steers which gained 3.04 pounds per day. No statistically significant difference was found between SBM and Bactolac. Consequently, Bactolac and SBM were very similar as feeds for beef cattle while urea fell short of that performance.

Huber and coworkers (11) of Michigan State University conducted another comparative study of Bactolac, SBM, and urea on dairy cattle. They used 30 Holsteins per treatment and set the crude protein for the treatments at approximately 14 percent and is calorically balanced. These cattle were on 46 percent shelled corn and 54 percent corn silage diet. Figure 3 illustrates that persistency of production during the 12-week experimental period was 90 percent for Bactolac, 89 percent for SBM, and 92 percent for the urea

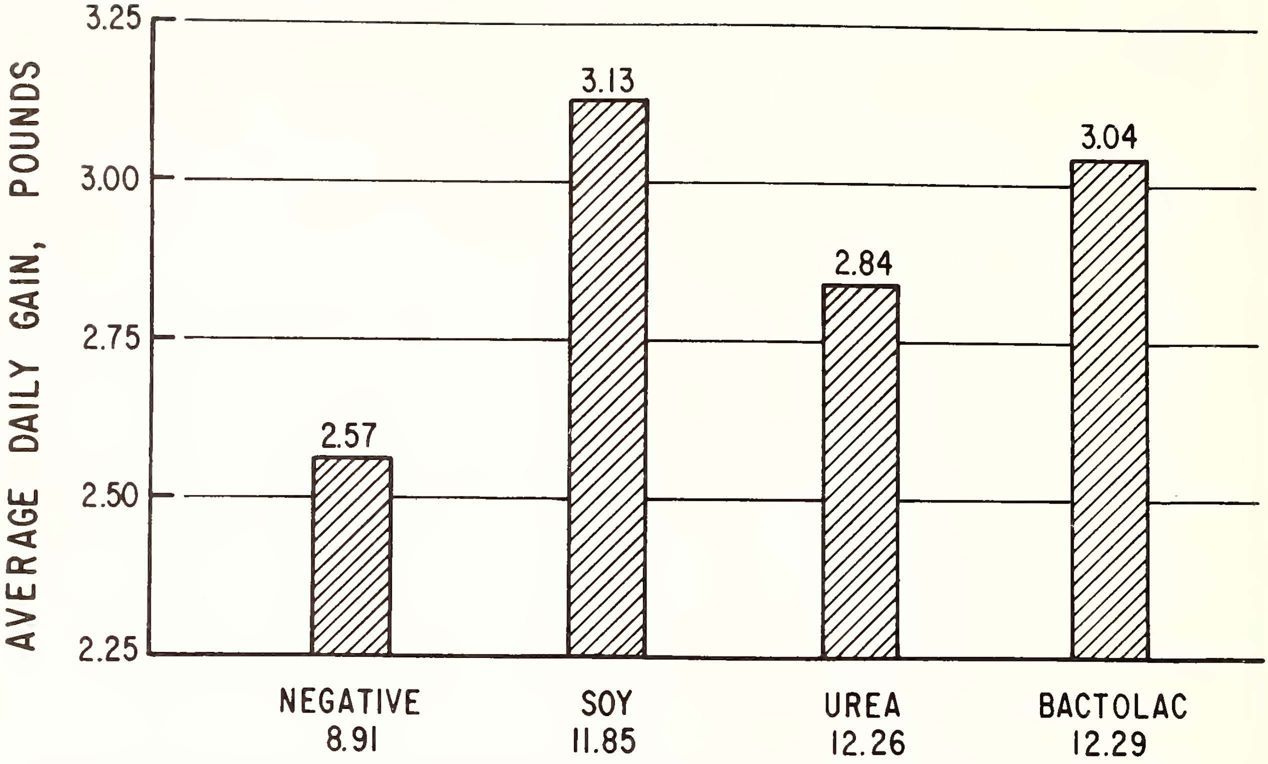


Figure 3.--Effect of isonitrogenous levels of soybean oilmeal, urea, and Bactolac on the persistency of milk production (10).

supplemented group. No statistically significant differences were observed between the three test groups. Huber and coworkers concluded in this one trial (with dairy cattle) that both Bactolac and urea were equivalent sources of crude protein to SBM when energy is balanced.

Together these studies illustrate that Bactolac is similar in effect to SBM for dairy and beef cattle.

Overall, Bactolac has consistently proved to be superior to urea and similar to soybean oilmeal when fed to beef and dairy cattle. Therefore, it is not unreasonable to speculate that Bactolac can replace a high percentage of the NPN and natural protein now being fed to cattle and can compete at a price level which yields favorable economics.

Before Bactolac can enter the marketplace, Food and Drug Administration approval is required. A petition has been filed with the FDA and at this time we are hopeful that it will be approved. In this application, both safety and efficacy of the product is being examined and regulations governing the maximum level of Bactolac for inclusion in feeds needs to be set.

Although some controversy concerning how much NPN can be utilized by ruminants exists, the scientific community generally concluded that NPN can be efficiently utilized to increase the CP content of a basal ration for beef and dairy cattle to at least 12 percent of the dry-matter intake without impairing production efficiency. Accordingly, we have proposed that the maximum level of Bactolac used should not exceed one-third of the total ration protein.

The production of whey in the United States is about 30 billion pounds per annum. This causes a considerable environmental problem. On the other hand, the demands for nitrogen supplements in the animal feed market is considerable and is rising.

As natural proteins are increasingly required for human foodstuffs, the alternative NPN products must take their place in animal rations. Bactolac, thus turns a pollution problem into an animal feed solution.

The whey industry is clearly faced with a difficult waste disposal problem of increasing magnitude. Quite properly, this industry is seeking to solve this problem in such a manner so as not to underutilize the inherent value and at the same time not to increase the price of cheese. A number of us feel that the most tenable route is to seek methods which "add value" to whey and which will place it in a different sector of the market structure. In other words, whey should be used as a feedstock for some new process and not treated as a material in need of disposal.

Fermentation routes such as those for producing single-cell-protein (yeast processes), the production of alcohol (wine), and the process described here seems to offer a route of high success probability.

From our standpoint, the production of Bactolac appears to be very promising. The advantages of Bactolac can be summarized as follows:

1. Production of Bactolac adds value to the whey making it more valuable than dry whey in ruminant animal feeds.

2. Bactolac is similar to SBM in both energy and crude protein.

3. Efficacy studies show that SBM and Bactolac are equivalent or superior to urea.

4. Deproteinized whey could be converted to Bactolac and there is no apparent reason why Bactolac and protein removal operations need not be compatible.

5. Conversion of whey to Bactolac is environmentally clean and economically efficient.

All aspects of whey utilization as animal feed and the details of Bactolac manufacture was not possible. However, I hope that sufficient information were presented to enable you to evaluate the possibilities of this process. In my judgment, Bactolac is not the only answer to the whey problem but it certainly appears to be a good one, particularly when the market potential greatly exceeds the surplus whey.

LITERATURE CITED

(1) Alston, E. M., Jr., W. B. Anthony, J. P. Cunningham, Jr., and G. J. Cottier. 1973. Production of nitrogen-enriched whey for animal feed. J. Anim. Sci. 36: 208 (Abstr.)

(2) Arnott, D. R., S. Patton, and E. M. Kesler. 1958. A method for manufacturing a high-nitrogen-low-lactose production from whey. J. Dairy Sci. 41: 931.

(3) Boyd, L. M. 1974. Whey in animal feed, Proceedings Whey Products Conference, 1974. 123 pp.

(4) Czarnetzky, E. J. 1954. U.S. Patent Office, No. 2,904,437.

(5) Hazzard, D. G., E. M. Kesler, D. R. Arnott, and S. Patton. 1958. Use of high-nitrogen feedstuff made from whey in the rations of dairy animals. J. Dairy Sci. 41: 1439.

(6) Henderson, H. E., R. Crickenberger, and C. A. Reddy. 1973. Research Report 245, Michigan State University Agriculture Experiment Station, East Lansing. pl.

(7) Henderson, H. E., R. G. Crickenberger, and C. A. Reddy. 1974. Effect of fermented, ammoniated condensed whey on dry matter consumption. J. Dairy Sci. 57: 635 (Abstr.)

(8) Henderson, H. E., C. A. Reddy, and R. G. Crickenberger. 1974. Fermented ammoniated condensed whey (FACW) as a protein source. J. Anim. Sci. 39: 240 (Abstr.)

(9) Huber, J. T., R. L. Boman, H. E. Henderson. 1974. Value of fermented-ammoniated whey as a nitrogen supplement for lactating cows. J. Dairy Sci. 57: 635 (Abstr.)

(10) Huber, J. T., R. L. Boman, and H. E. Henderson. 1976. Fermented ammoniated condensed whey as a nitrogen supplement for lactating cows. J. Dairy Sci. 59: 1936.

(11) Huber, J. T., R. L. Boman, H. E. Henderson, and G. W. Kulasek. 1975. Fermented ammoniated whey as a nitrogen supplement for lactating cows. J. Dairy Sci. 58: 748 (Abstr.)

(12) McCullough, M. E., W. E. Neville, Jr., and W. J. Monson. 1972. Ammoniated whey as an ingredient in complete livestock rations. Feedstuffs 17: 27.

(13) Moore, L. D., and W. B. Anthony. 1971. Lactic acid fermentation and ammonification of animal feeds. J. Anim. Sci. 32: 388 (Abstr.)

(14) Reddy, C. A., H. E. Henderson, and M. D. Erdman. 1975. Production of a feed supplement high in crude protein by bacterial fermentation of cheese whey. The Ann. Meet. Amer. Soc. for Microbiol. p. 196. (Abstr.)

(15) Schingoethe, D. J. 1976. Whey utilization in animal feeding; A summary and evaluation. J. Dairy Sci. 59: 556.

NEW USES FOR LACTOSE

F. W. PARRISH

USDA, Eastern Regional Research Center
Philadelphia, PA 19118

An approach to the use of whole whey is to examine ways of using its components, namely, protein and lactose. Yesterday we heard talks illustrating the advances in electromembrane processing and ultrafiltration for protein isolation. The waste streams from these processes contain lactose. Two projects aimed at converting lactose into useful derivatives--formation of lactose esters and isomerization of lactose to lactulose--are conducted at our Eastern Regional Research Center.

The magnitude of the annual whey surplus has been estimated (15) at 36 billion pounds (2.4 billion pounds of solids) which translates to 1.7 billion pounds of lactose (9). Approximately 50 percent of this whey is discarded (6, 13). Our philosophy in looking for marketable products derived from lactose is that the products must be formed in high yield from relatively simple reactions and techniques.

To a carbohydrate chemist, the following reactions of lactose would be classified as simple reactions:

1. REDUCTION to form LACTITOL. ICI America produces this material. This conversion gives a product which is much less susceptible to degradation under alkaline conditions than is lactose.

2. OXIDATION to form various acids. Oxidation can be effected with enzymes from microorganisms or by air oxidation to produce, for example, lactobionic acid.

This simple oxidation product of lactose may find application in boiler scale prevention and as a corrosion inhibitor. Further oxidation is possible to form higher carboxylic acids.

3. GLYCOSIDATION to form methyl lactoside. The reaction between lactose and methyl sulfate at pH 12 gives methyl lactoside in 90 percent yield, the product consisting of 78 percent β- and 22 percent α-anomer. At present we do not have any ideas for novel uses of this product, but the product is unreactive with alkali or with amino acids and protein.

4. ESTERIFICATION to form surfactants and emulsifiers. Historically, esters of carbohydrates can be traced back to 1880 when sucrose octaacetate was prepared. This compound has an intensely bitter taste and it found minor use in denaturing alcohol. As H. B. Hass has stated (10), "If it doesn't keep the nurses and interns from drinking the rubbing alcohol in the hospital it at least keeps them from enjoying it." Concerted efforts to develop procedures for the preparation of esters of sucrose with long-chain fatty acids began in September 1952, sponsored by the Sugar Research Foundation,

primarily by Foster D. Snell, Inc. A decade later a patent was granted to Eastman Kodak Co. (22) for the preparation of mixed esters of acetic, propionic, and isobutyric acids with lactose. In these products all eight hydroxyl groups of lactose were esterified, and the products were incorporated into cellulose acetate (up to 25 percent lactose ester) or cellulose acetate butyrate (up to 50 percent lactose ester) to form clear, hard, flexible film whereby higher Sward hardness rating was obtained compared with film not modified with lactose ester.

The objective of the Sugar Research Foundation program was to obtain detergents from sucrose, and in order to have the proper hydrophilic-lipophilic balance (HLB) for good detergency, only one or two of the hydroxyl groups of sucrose should be esterified. The process comprised formation of sucrose esters by transesterification with the methyl ester of a fatty acid in N,N-dimethylformamide as solvent and with potassium carbonate as catalyst. The product contained 60 percent monoester and 40 percent diester.

Commercial development can be credited to the Japanese. In September 1959, Dai-Nippon Sugar Manufacturing Co. began construction of a sucrose ester pilot plant with a production capacity of 180 tons per year (12). Production began a year later, and the product found application in various food products. The capacity of the pilot plant was increased to 360 tons per year, then in April 1967 a new commercial plant with an annual capacity of 1,200 tons was completed in Yokohama. The demand for sucrose esters increased 15 to 20 percent per annum, and in 1974 Ryoto Co., Ltd. (the successor to Dai-Nippon Sugar Mfg. Co.) completed a new plant with an annual production capacity of 3,000 tons (14). The process development, current applications, and future potential of sucrose-based chemicals were the subject of a symposium of the Division of Carbohydrate Chemistry of the American Chemical Society at the 172d National Meeting (14). The papers presented at this symposium provide useful information applicable to corresponding esters derived from lactose.

Research and development of lactose esters as surfactants has been in progress at Eastern Regional Research Center since 1973 by Frank Scholnick and Warner Linfield. Initial attempts to form lactose esters followed the same transesterification procedure that had been used with sucrose, namely, the use of a fatty acid methyl ester in N,N-dimethylformamide with potassium carbonate as catalyst. However, no lactose ester was produced--much to their surprise. Furthermore, no ester was formed with methyl sulfoxide or N-methyl-2-pyrrolidone as solvent or with other catalysts, e.g., potassium t-butoxide, potassium hydroxide, or sodium methoxide (2). A successful approach to form lactose esters was the reaction of lactose in N-methyl-2-pyrrolidone as solvent with fatty acid chlorides resulting in crude yields of 88 to 95 percent for esters of lauric, myristic, palmitic, stearic, oleic, and tallow fatty acids. Chromatographic analysis showed that the principal product was monoester. It is important that the product be the monoester of lactose if detergents are the application under consideration, because diesters and higher esters of lactose are not soluble in water.

The failure to transesterify lactose with the methyl ester of fatty acids is attributed to the close proximity of the two primary alcohol groups of lactose, in contrast to the three primary hydroxyl groups of sucrose, necessitating the use of the more powerful acid chloride to form esters of lactose.

The lactose monoesters were also treated with ethylene oxide until 6 moles of ethylene oxide had reacted with the ester.

Detergency measurements were carried out in a Tergotometer on EMPA (cotton), Testfabrics (cotton-polyester with permanent press finish), and U.S. Testing (cotton) cloth using lactose esters and oxyethylated esters at concentrations of 0.10 and 0.02 percent at water hardness levels of 50 and 300 ppm. Comparison was made with sucrose monopalmitate and with Triton X-100 (alkyl phenoxy polyethoxy ethanol).

TABLE I.--Detergency data (0.1 percent concentration)

	ΔR[1] values					
	Testfabrics		EMPA		U.S. testing	
Compounds[2]	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O
Lactose laurate	19.6	17.5	8.9	12.6	8.3	8.4
Lactose laurate + E.O.	20.6	18.6	9.5	14.8	7.7	8.6
Lactose myristate	19.9	18.2	8.6	15.0	8.7	9.0
Lactose myristate + E.O.	19.3	19.2	9.4	15.1	8.0	8.8
Lactose palmitate	13.4	14.7	5.0	13.9	8.8	8.0
Lactose palmitate + E.O.	16.8	16.9	7.1	15.7	7.6	6.1
Lactose stearate	13.9	11.2	5.6	11.6	7.2	7.6
Lactose stearate + E.O.	16.2	13.7	8.6	12.6	6.9	8.2
Lactose oleate	14.7	16.1	4.4	10.4	8.7	7.4
Lactose oleate + E.O.	14.9	13.2	8.0	13.3	5.0	7.5
Lactose tallowate	14.4	16.1	7.6	13.7	7.3	7.0
Lactose tallowate + E.O.	12.5	12.5	7.4	11.4	6.3	6.4
Sucrose palmitate	17.6	17.2	5.9	13.4	7.2	7.6
Sucrose palmitate + E.O.	6.8	5.4	6.3	8.6	3.8	4.5
Control	25.8	25.3	7.3	11.7	9.3	10.0

[1] ΔR, increase in reflectance after washing.

[2] E.O. is ethylene oxide.

TABLE II.--Detergency data (0.02 percent concentration)

Compounds[2]	ΔR[1] values					
	Testfabrics		EMPA		U.S. testing	
	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O
Lactose laurate	14.0	11.8	7.2	11.5	6.9	6.3
Lactose laurate + E.O.	12.7	11.3	9.6	12.4	6.9	6.8
Lactose myristate	13.9	13.4	7.4	11.7	6.7	6.5
Lactose myristate + E.O.	14.4	13.6	10.6	11.4	7.7	7.0
Lactose palmitate	10.6	10.4	5.7	10.3	5.6	5.8
Lactose palmitate + E.O.	12.2	12.2	9.0	11.0	6.3	6.6
Lactose stearate	7.9	10.5	5.7	8.6	4.9	5.0
Lactose stearate + E.O.	9.6	9.9	7.6	9.9	5.6	6.1
Lactose oleate	12.5	11.1	5.9	9.9	6.6	5.7
Lactose oleate + E.O.	11.4	10.9	9.5	11.0	6.4	6.4
Lactose tallowate	9.4	8.1	8.5	10.4	5.3	5.3
Lactose tallowate + E.O.	11.3	8.8	5.8	8.5	4.4	4.3
Sucrose palmitate	15.1	14.9	7.3	11.4	5.8	6.5
Sucrose palmitate + E.O.	3.3	3.0	6.0	7.3	2.6	3.7
Control	16.1	14.7	7.7	12.1	6.7	7.4

[1] ΔR, increase in reflectance after washing.

[2] E.O. is ethylene oxide.

Two other surface active properties were measured, emulsion stability and lime soap dispersant requirement (l.s.d.r.).

The lastose esters and their oxyethylated derivatives possess surfactant properties comparable to those shown by analogous sucrose derivatives. In general, the lower fatty acid esters of lactose (i.e., laurate, myristate, and palmitate) showed the best detergency properties, probably because of increased solubility, but no great improvement was evident for the oxyethylated lactose esters. Greater emulsifying power, as shown by longer emulsion times in Table III, was displayed by the higher molecular weight members of the fatty acid series because of their greater lipophilic bulk. No advantage in performance was gained by addition of ethylene oxide. Best l.s.d.r. was shown by lower molecular weight members of the series, probably because of greater water solubility. This is supported by the fact that the ethylene oxide adducts of the lactose esters show improved l.s.d.r. over those that are not oxyethylated.

Lactitol, obtained by reduction of lactose, can be esterified in N,N-dimethylformamide by transesterification with the methyl esters of fatty acids in contrast to lactose (20). The process of transesterification of lactitol offers some advantages over the esterification of lactose with a fatty acid

TABLE III.--Surface active properties

Compounds[1]	Emulsification time (sec)	Lime soap dispersant requirement (percent)
Lactose laurate	17	9
Lactose laurate + E.O.	95	8
Lactose myristate	23	9
Lactose myristate + E.O.	14	9
Lactose palmitate	198	15
Lactose palmitate + E.O.	62	10
Lactose stearate	63	30
Lactose stearate + E.O.	52	13
Lactose oleate	214	11
Lactose oleate + E.O.	97	9
Lactose tallowate	190	17
Lactose tallowate + E.O.	178	11
Sucrose palmitate	180	11
Sucrose palmitate + E.O.	103	21
Control	52	4

[1] E.O. is ethylene oxide.

chloride and pyridine to scavenge the hydrogen chloride which is liberated. The use of two noxious reactants, namely, pyridine and fatty acid chloride, is obviated, and lactitol does not have the sensitivity to alkaline catalysts, e.g., potassium t-butoxide, that lactose shows.

Products which were mainly monoesters, were obtained with methyl esters of lauric, palmitic, stearic, and tallow fatty acids. The lactitol monoesters were also treated with ethylene oxide until 6 moles of ethylene oxide has been incorporated into the ester.

Surface-active properties were examined for these materials in the same way as was done for the corresponding lactose products. The results are summarized in Tables IV - VI.

The lactitol esters are slightly better detergents than the corresponding lactose esters, but again no improvement was evident with ethylene oxide adducts.

Lactitol esters were generally inferior to lactose esters in the ATLAB emulsion test, but the addition of ethylene oxide to the lactitol esters improved the emulsifying power greatly, in marked contrast to the behavior with lactose esters. On the other hand, lactitol esters were somewhat inferior to the corresponding lactose esters in the l.s.d.r. test, and addition of ethylene oxide gave only slight improvement.

TABLE IV.--Lactitol esters detergency data (ΔR)[1]

Compounds and concentrations	Testfabrics		EMPA		U.S. testing	
	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O
Laurate (0.1%)	18.5	17.0	11.0	12.2	8.9	8.8
Laurate (0.02%)	5.5	3.7	4.3	7.5	1.7	3.2
Palmitate (0.1%)	20.0	19.9	6.5	11.2	10.2	10.0
Palmitate (0.02%)	15.2	16.1	8.1	13.3	9.5	8.3
Stearate (0.1%)	21.3	20.6	7.3	11.0	11.2	10.3
Stearate (0.02%)	14.1	18.1	7.2	12.3	8.4	8.7
Tallowate (0.1%)	21.4	19.6	6.2	12.0	10.2	9.5
Tallowate (0.02%)	16.1	17.6	9.0	13.1	8.3	8.4
Control[2] (0.1%)	25.3	26.0	8.8	11.3	9.2	10.9
Control (0.02%)	15.5	18.1	7.5	12.6	7.6	8.8

---

[1] ΔR = increase in reflectance after washing.

[2] Triton X-100.

TABLE V.--Ethoxylated lactitol esters detergency data (ΔR)[1]

Compounds and concentrations	Testfabrics		EMPA		U.S. testing	
	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O	300 ppm H_2O	50 ppm H_2O
Laurate (0.1%)	15.1	14.6	10.2	13.4	8.1	9.3
Laurate (0.02%)	3.0	4.7	4.1	5.9	2.2	3.3
Palmitate (0.1%)	19.4	17.2	5.6	10.7	9.2	10.0
Palmitate (0.02%)	17.7	15.1	8.0	13.6	8.7	8.8
Stearate (0.1%)	19.1	19.1	8.0	13.2	9.9	10.2
Stearate (0.02%)	15.7	14.5	7.7	12.4	9.0	8.1
Tallowate (0.1%)	19.4	18.4	5.9	12.5	9.0	10.9
Tallowate (0.02%)	16.2	15.5	8.8	12.7	8.7	9.0
Control[2] (0.1%)	25.3	26.0	8.8	11.3	9.2	10.9
Control (0.02%)	15.5	18.1	7.5	12.6	7.6	8.8

---

[1] ΔR = increase in reflectance after washing.

[2] Triton X-100.

TABLE VI.--Lactitol esters surface-active properties

	Atlab emulsification time (sec)	LSDR[1] (%)
Laurate	14	19
Laurate + E.O.[2]	23	18
Palmitate	113	18
Palmitate + E.O.	234	16
Stearate	66	19
Stearate	272	14
Tallowate	67	11
Tallowate + E.O.	250	9
Control[3]	52	4

[1] LSDR = lime soap dispersant requirement.

[2] E.O. = ethylene oxide.

[3] Triton X-100.

When transesterification is performed after addition of ethylene oxide to lactitol, good emulsifiers are produced. These products have a structural resemblance to Tweens (Atlas Chemical Industries, Inc.) which are fatty acid esters of oxyethylated sorbitan.

Esters of lactose or lactitol, with or without addition of ethylene oxide, are readily biodegradable (20), as evidenced by loss of carbon and increase in surface tension, comparison being made with sodium hexadecyl sulfate. Lactitol derivatives are biodegraded slightly faster than lactose derivatives.

Commercialization of sugar esters has been retarded because suitable solvents for the sugar (e.g., methyl sulfoxide, dimethylformamide, N-methyl pyrrolidone) are expensive, losses of solvent occur in processing, and traces of solvent in the product invalidates their use as food emulsifiers. Consequently, in recent years considerable attention has been given to reactions to form sugar esters in which the use of these expensive and toxic solvents is avoided.

A process was developed (17) which enables reaction to occur between two immiscible liquid reactants in the presence of an emulsifying agent to form a transparent emulsion. Reaction rates in transparent emulsions are of the same order as in homogeneous solution, whereas reactions of immiscible reactants in opaque emulsions are generally too slow to be of practical value. For example, sucrose monostearate was prepared by forming a micro-emulsion with sucrose, methyl stearate, and sodium oleate as emulsifying agent. Potassium carbonate was added as catalyst, and the reaction proceeded as does conventional transesterification. The products meet the Japanese Food Additive Standard which requires free sugar not to exceed 10 percent and methanol (free or combined) not to exceed 10 ppm (14).

Another process that does not require the solvents previously mentioned has been developed by Feuge and his coworkers at USDA's Southern Regional Laboratory, New Orleans, LA (5). Molten sucrose and fatty acid esters react at 170° to 187°C in the presence of lithium, sodium, or potassium soaps as catalysts and solubilizers. The transesterification reaction is completed in 12 minutes or less.

Our own approach to solvent-free transesterification involves the reaction of isopropenyl esters of fatty acids with lactose in the presence of toluenesulfonic acid as catalyst. The reaction is performed below 135°C, and the products are lactose esters and acetone. Study of isopropenyl esters was initiated by E. S. Rothman (19) at Eastern Regional Research Center, and the formation, reactions, and applications of these isopropenyl esters have been investigated extensively in our laboratories.

5. ISOMERIZATION of lactose to lactulose. The isomerization of lactose to lactulose with calcium hydroxide has long been known (16), but the method suffers from low yield (15 percent), long reaction time (several days at 35°C), and difficulties in isolation of product. Similar difficulties were found when isomerization with ammonia was attempted (11), the yield of lactulose being only 12 percent. In 1949 sodium aluminate was used to treat corn sirup (4) whereby conversion of some glucose to fructose occurred to produce an extra sweet corn sirup that did not crystallize. Subsequently, the use of sodium aluminate was extended to the isomerization of glucose to fructose (8), and lactose to lactulose (7), with yields of 67 and 80 percent, respectively. These conversions constitute a major advance in terms of yield of product, but product recovery from the large quantity of sodium aluminate is somewhat difficult. Rendleman and Hodge (18) have used columns of anion-exchange resin in the aluminate form to obtain lactulose in 41 percent yield in 4 hours at 25°C, but their procedure has practical limitations because of the large quantities of water required to elute sugars from the column.

Our approach to the isomerization of lactose to lactulose entails the use of triethylamine. The experimental conditions and product yield are shown in Table VII.

The thrust of our investigations is to devise a practical process for the isomerization of lactose to lactulose with triethylamine and to find uses for the product in food and nonfood applications.

The following lists diverse potential applications of lactose esters and lactulose:

Detergents and emulsifiers

Pharmaceuticals

Polyurethane intermediates and coatings

Drying oils

Plastics--adhesives, sealants

Pesticides

Chemicals by fermentation

TABLE VII.--Conversion of lactose to lactulose with triethylamine

Percent net$_3$	Solvent	Temperature °C	Percent yield
1	H_2O	25	27
1	H_2O	50	35
2	$CaCl_2/CH_3OH$	25	29
2	$CaCl_2/CH_3OH$	50	37
5	$CaCl_2/CH_3OH$	50	53
2	$CaCl_2/H_2O$	25	73

Obviously, we would like to find innovative and unique applications for lactose-derived products, rather than to imitate the uses of sucrose-based materials. For example, Richardson-Merrell, Inc., developed the use of lactulose for the treatment of portal-systemic encephalopathy, a syndrome of chronic liver disease (3). In the colon, lactulose is metabolized by bacteria into organic acids, mainly lactic acid, which lower the pH of the colonic contents and promote the diffusion of ammonia from the blood into the colonic lumen where the ammonia is trapped. Removal of ammonia from systemic circulation prevents its deleterious action in the brain.

Lactose has been examined as a substitute for sucrose in bakery goods (1) and was found wanting in those applications that require sweetness or solubility in the sugar components. Lactulose will not contribute sweetness properties, but its high solubility in water (>70 percent) warrants its further study in bakery and confectionery applications. It would be advantageous if a lactose isomerase were to be found, analogous to glucose isomerase which has so revolutionized the sweetener industry (2).

To summarize, we feel confident that our scientific investigations will lead to commercial possibilities for lactose and its derivatives, and in this way will contribute to the problem of whey utilization.

LITERATURE CITED

(1) Ash, D. J. 1976. Research on lactose indicates uses, limitations as a substitute for sucrose in bakery goods. Food Product Development 10: 85.

(2) Casey, J. P. 1976. High fructose corn sirup--a case history of innovation. Research Management 19: 27.

(3) Elkington, S. G., M. H. Floch, and H. O. Conn. 1969. Lactoluse in the treatment of chronic portal-systemic encephalopathy. New Eng. J. Med. 281: 408.

(4) Fetzer, W. R., and J. W. Evans (to Union Starch and Refining Co.). 1949. Extra sweet corn sirup. U.S. Patent 2,487,121.

(5) Feuge, R. O., H. J. Zeringue, Jr., T. J. Weiss, and M. Brown. 1970. Preparation of sucrose esters by interesterification. J. Amer. Oil Chem. Soc. 47: 56.

(6) Groves, F. 1972. An economic analysis of whey utilization. In Proceedings, Whey Products Conference, Chicago, Ill., June 14-15, 1972. U.S. Dept. Agr. ERRL Pub. 3779, pp. 5-18.

(7) Guth, J. H., and L. Tumerman (to Kraftco Corp.). 1970. Lactulose from lactose. U.S. Patent 3,546,206.

(8) Haack, E., F. Braun, and K. Kohler (to C. F. Boehringer and Soehne G.m.b.H). 1966. D-Fructose. U.S. Patent 3,256,270.

(9) Hargrove, R. E., F. E. McDonough, D. E. LaCroix, and J. A. Alford. 1976. Production and properties of deproteinized whey powders. J. Dairy Sci. 59: 25.

(10) Hass, H. B. 1968. Early history of sucrose esters. Sugar esters (Noyes Development Corp., Park Ridge, N.J.), p.1.

(11) Hough, L., J. K. N. Jones, and E. L. Richards. 1953. The action of ammonia on glucose, maltose, and lactose. J. Chem. Soc. 2005.

(12) Iwatsuki, H. 1968. Present status of processes for production of esters. Sugar esters (Noyes Development Corp., Park Ridge, N.J.), p. 17.

(13) Johnson, K. T., C. G. Hill, and C. H. Amundson. 1976. Electrodialysis of raw whey and whey fractionated by reverse osmosis and ultrafiltration. J. Food Sci. 41: 770.

(14) Kosaka, T., and T. Yamada. 1976. 172nd American Chemical Society National Meeting, San Francisco, Calif. Aug. 29-Sept. 3. Symposium on sucrochemistry. (Abstract No. CARB 72.)

(15) Lough, H. W. 1974. The cheese industry. U.S. Dept. Agr., Econ. Res. Serv., Agr. Econ. Rpt. No. 294.

(16) Montgomery, E. M., and C. S. Hudson. 1930. Synthesis of lactulose from lactose. J. Amer. Chem. Soc. 52: 2101.

(17) Osipow, L. I., and W. Rosenblatt (to State of Nebraska). 1969. Glycerol and sugar esters. U.S. Patent 3,480,616.

(18) Rendlemen, J. A., Jr., and J. E. Hodge. 1975. Complexes of carbohydrates with aluminate ion. Carbohydrate Res. 44: 155.

(19) Rothman. E. S. 1968. Reactions of the stearoylated enolic form of acetone involving hexadecylketene as the reactive intermediate. J. Amer. Oil Chem. Soc. 45: 189.

(20) Scholnick, F., G. Ben-Et, M. K. Sucharski, E. W. Maurer, and W. M. Linfield. 1975. Lactose-derived surfactants. Fatty esters of lactitol. J. Amer. Oil Chem. Soc. 52: 256.

(21) Scholnick, F., M. K. Sucharski, and W. M. Linfield. 1974. Lactose-derived surfactants. Fatty esters of lactose. J. Amer. Oil Chem. Soc. 51: 8.

(22) Touey, G. P., and H. E. Davis (to Eastman Kodak Co.). 1962. Mixed esters of lactose. U.S. Patent 3,030,356.

PROGRESS IN INTERNATIONAL DAIRY FEDERATION WHEY PROGRAMS

B. H. BLANC

Commission Suisse du Lait
Liebefeld-Bern, Switzerland

Over the past five years, the IDF's interest in whey processing and utilization has actively increased, thus leading to the formation of a first group of experts on this matter. As Chairman of this group, I am very pleased to have the opportunity to address this international audience.

The International Dairy Federation formed in 1903 now consists of 29 member countries with a dairy industry of particular importance. They represent all parts of the world with the notable exception so far, of the United States of America.

Each member country has a national committee, which represents as many national dairying interest as possible. acting as the representative of the IDF in that country and being responsible for any approach to the government or any other national body.

The technical and scientific work of the Federation, which may be any subject supported by at least four member countries, is carried out through six basic commissions with their individual groups of experts.

The commissions treat the following subjects:

Commission	
A	Production of milk, hygiene.
B	Technology and engineering.
C	Economics and management techniques.
D	Legislation, compositional standards, classification, terminology.
E	Analytical standards, laboratory techniques.
F	Science and education.

Problems arising in connection with the work of all commissions are discussed in the commission of studies and all activities are coordinated by a permanent secretary general who is based in Brussels.

Apart from many individual meetings and seminars, the IDF convenes in annual sessions that all commissions, the commission of studies and the general assembly are invited to attend. The 1976 sessions were held in Quebec City last week where some 300 dairy experts gathered.

The IDF is also responsible for the organization of the International Dairy Congress which is held every four years and attended by 2,500 to 4,000 delegates. The 1970 Congress took place in Sydney, the 1974 Congress in New Delhi, and in 1978, planned for Paris.

Among the numerous publications of the IDF are the annual Bulletin that includes reports and standards approved at the previous annual sessions, a collection of at least 70 standardized methods, a 500-page analytical book on "The Control of Mastitis" and a 200-page document on lipolysis.

An intensified cooperation, which is one of the IDF's main concerns with other international organizations such as IAO, WHO, UNICEF, ISO, and AOAC, is becoming increasingly successful.

Within commission B, two groups of specialists now deal with whey processing. One of these is the newly formed group B_{26}, which is to study all aspects of membrane processors and resulting products including:

A survey of all available equipment.
Definitions of nomenclature and standards of performance.
Guidelines for testing equipment.
Characteristics of obtained products and disposal problems for byproducts.

Our own group B_{11} is concerned with the more general aspects of whey processing and utilization while maintaining close contacts with group B_{26} through joint meetings and owing to the pertinence of some members to both groups.

The group includes representatives of the following countries: Australia, Austria, Belgium, France, Ireland, Germany, Netherlands, New Zealand, Sweden, United Kingdom, and Switzerland. It is a special pleasure to have a representative of the United States as well as Dr. Clark of the Whey Products Institute. It is also planned to appoint a member from Japan.

Considering the large amount of work that has to be done, we have to restrict ourselves only to those points that allow us to prepare reports of practical importance--if we want to remain effective.

In the course of six meetings so far, the last one having taken place in Atlantic City this week, various practical and economic aspects of whey utilization were discussed. As a starting point, the group prepared a questionnaire completed by the majority of IDF member countries. The subject covered such aspects as:

- whey volumes produced by category
- seasonal variations in whey volumes
- analytical data on the various types of whey and test methods used
- main outlets for whey utilization

The initial survey covered the year 1972. To establish trends over the past 5-year period, we intend to issue a new questionnaire for 1977.

One of the main tasks of group B_{11} consists in establishing international compositional standards for whey powders. We initially concentrate on producing standards for basic whey powders, but later we expect to include the other derivatives of whey, such as delactosed and demineralized whey powders.

Emphasis is being put on the elaboration of compositional standards, which must not be confused with customer specifications. Procedures and formulas for dealing with compositional standards within the IDF organization are already established. They generally consist of:

- general description
- analytical data
- list of authorized additives
- labelling requirements and packages

We are aware that IDF standards need to be adjusted to those of the American Whey Products Institute in order to give them a truly international status. This, of course, would also facilitate their acceptance by the joint FAO/WHO expert committee of the Code of Principles on Milk and Milk products and perhaps further in the Codex alimentarius.

Before moving on to whey powders, the IDF as well as the Whey Products Institute found it necessary to define whey, both acid and sweet.

Definitions

Whey is the fluid obtained by separating the coagulum from milk, cream, or skimmed milk and from which a portion of the milk fat may have been removed.

This definition then is subdivided into--

- Acid whey is the whey arising from products in which the coagulum formed principally by acidification. If mineral acid is used, the whey is referred to as mineral acid whey.
- Sweet whey is the whey arising from products in which principally rennet-type enzymes are used to obtain the coagulum.

Having defined whey, we now specify whey powder as being the product derived from whey by drying, the words acid or sweet being used to prefix whey as appropriate. Although the data for moisture and fat are the same for both acid and sweet whey powders, there are important differences in the four other retained specifications, as shown below:

Analytical Data of Whey Powders

	Acid whey powder	Sweet whey powder
Moisture in percent	4.5 max.	4.5 max.
Fat in percent	1.5 max.	1.5 max.
Ash in percent	14.0 max.	9.5 max.
Lactose in percent	60.0 min.	65.0 min.

Protein in percent	10.0 min.	11.0 min.
pH (10 percent solution)	5.1 max.	5.6 min.

The survey, which lead to these values, was not only conducted within the group but among all IDF member countries. The group is aware that the testing methods will have to be specified; but, in several cases, they still are a matter of discussion in other commissions (D and E) or organizations (AOAC/ISO).

To cover physical appearance, flavor and odor, the group decided that they could do no better than copy the proposals of the American Whey Products Institute, stating that it:

> Has a uniform light color and is free from lumps that do not break up under moderate pressure. Free from nonwhey flavors and odors.

The question of additives can vary from country to country and, therefore, we are now conducting a survey in member countries on the additives that are legally authorized. Specifically, we are interested in such additives as permitted free-flow agents.

The definition of additives is not intended to include such compounds as nitrates and nitrites which, if necessary, would be subject to specific customer requirements. The reason I mentioned nitrates is because it is common practice in some parts of Europe for such compounds to be added to the milk before cheesemaking in order to reduce the danger of the cheese blowing because of a late development of clostridid agents. A large proportion of the added nitrate remains in the whey.

On a similar basis, bacteriological standards have not been included, although they are likely to be required at a later stage, if only to distinguish between the subcategories of animal feed grade and human food grade powders.

In due time this matter will be referred to the special committee on hygiene in foods (FAO/WHO). However, current indications are that a standard plate count of 100,000 per gram and 10 coliforms per gram will be called for.

Appropriate authorities will be charged with the clarification of labelling practices, but we would expect them to include the category of whey (sweet, acid, or mineral acid), the type of drying operation (roller or spray), and the list of any added ingredients.

The work done by group B_{11} of the IDF and the American Whey Products Institute will contribute to a better commercial understanding of whey and whey powders worldwide--thus boosting trade in this important byproduct of cheese.

AUSTRALIAN WHEY RESEARCH PROGRAMS

L. L. MULLER

Dairy Research Laboratory, CSIRO
Melbourne, Australia

In the year ending June 30, 1976, Australia produced about 1,400 million litres of whey--1,000 million from manufacture of cheese and 400 million from casein or coprecipitate manufacture. The amount of whey solids involved, some 85,000 tonnes, may seem rather small in relation to the USA total. However, the extent of the whey problem is relatively greater in Australia for two important reasons:

1. Some 60 percent of the whey-producing products were exported. Hence, to market all Australia's whey solids within the country would represent 2.5 times the challenge facing the United States of America.

2. Dairy farming in Australia is based on the grazing of pasture, particularly where milk for manufacture is concerned. The result is a marked seasonal variation in the quantity of milk available for manufacture. Ratios of 10 or 15 to 1 between peak and trough are common outside the fluid milk sector. Add to this the common trend towards diversification of products within a dairy company and the situation is reached where equipment for manufacture of whey products may be utilized for only 30 percent of the hours in a year. This can be compared with the 70 percent utilization of equipment in countries such as the United States where lot feeding of dairy cows is normal. We, therefore, face about twice the capital costs per tonne in manufacturing whey products.

These facts were clearly demonstrated in Australia during early studies of the feasibility of whey utilization by the conventional processes for making dried whey, demineralized whey, and yeast (10,11).

Offsetting these adverse factors to some extent were the possibilities for use of whey in liquid form for animal feeding or for its disposal by irrigation of land. However this outlet would obviously be reduced progressively as more attention was given to overcoming environmental pollution. The dairy industry in the main manufacturing state, Victoria, realized this and some manufacturers formed a group to sponsor a research programme (1,5).

Research workers from two Divisions of CSIRO - Food Research and Chemical Engineering and from the Victorian Department of Agriculture realized that an effective approach to a problem of this magnitude required a multidisciplinary, collaborative effort. Indeed, it soon became apparent that the scope of the task was so great that international collaboration was needed as well, especially with countries such as New Zealand and Ireland where grazing of pasture is also the normal approach to feeding of dairy cows. The Australian workers are most grateful for the international collaboration. Much time and effort were saved to choose some phases of the programme on which to concentrate.

I will confine my review to the Australian whey research programme. Muller in 1972 (7) summarized the task as: (1) expansion of the existing markets for whey through creation of new and improved products; (2) aiming to increase the average value of whey solids; and (3) reducing the costs of manufacture. The recent developments in membrane technology were considered to provide scope for achievement of these objectives. The research programme was, therefore, organized with priority being given to study of the membrane processes of ultrafiltration and reverse osmosis. This decision was based on objective 2, aiming to increase the average value of whey solids. It seemed obvious that success in this objective depended on a fractionation process to produce protein-rich materials on the one hand and on the other to provide a relatively pure, protein-free raw material for other processes.

Progress in the collaborative programme to date has been encouraging and can be summarized.

ULTRAFILTRATION

The experimental work on ultrafiltration (UF) was begun at the start of 1972. At this stage a number of early publications and a few reports of commercial-scale trials indicated that the capital costs of the process could be unacceptably high for Australian conditions. High performance per dollar invested was a prime requirement.

Comparative studies with a range of ultrafiltration plants (9) showed that permeation rates per m^2 of membrane varied between the types of equipment examined and that there were major differences in performance with types of whey. At their normal pH values, acid casein whey averaged about 50 percent of the performance of Cheddar cheese whey. Both wheys gave low permeation rates at pH 4.1 to 4.4 and high rates at pH values below 3.0. As the pH was increased above 5.0 permeation rates improved with Cheddar cheese whey but there was little improvement with casein whey. These differences in performance with type of whey and pH were obviously related to changes in the nature of the deposit which formed on the membrane surface during ultrafiltration (UF).

Whey Pretreatments

Hayes, Dunkerley, Muller, and Griffin (6) found that UF performance could be considerably improved by whey pretreatment involving heating and pH adjustment. This pretreatment caused formation of aggregates of the higher molecular-weight proteins and some of the β-lactoglobulin.

The choice of pretreatment conditions depended on the type of whey and the properties desired in the whey protein concentrate. Acid casein whey contains most of the minerals of the original milk in the correct proportions to form complexes known as apatites when the pH is increased beyond 5. At pH values around 5.2 to 5.9, apatite formation and aggregation of protein on heating the whey to 80°C was not excessive. The whey and subsequent protein concentrate (WPC) approached the whiteness of milk and the dried WPC had a solubility similar to nonfat milk solids as judged by the usual American Dry Milk Institute method. Acid whey so pretreated, therefore, gives a WPC with physical properties somewhat like those of nonfat milk solids. The pretreatment approximately doubles UF performance as compared with pasteurized acid whey.

The level of calcium in sweet cheese whey is less than half that of acid wheys. It was therefore possible to take advantage of the beneficial effects of higher pH on flux rate. When the pH is around 7.0, fouling by apatite appears to become a factor at this level of calcium.

However, the flux curves with sweet cheese whey at pH 6 to 7 still show a decline with time due to gel formation. Hayes and coworkers (6) found that this could be overcome by either heating at 85°C/15s at the natural pH of the whey, >5.8, or by reducing the pH to about 5.2, heating at 80°C/15s then increasing the pH to about 5.9. The second treatment involves less denaturation of protein but, as there are two pH adjustment steps, the reason for improvement is a little more complicated.

A further pretreatment found useful was demineralization. Hayes and coworkers (6) reported on the effect on flux rate at various pH values of using ion exchange to reduce the mineral content of HCl casein whey by about 95 percent. The improvement in flux rate was quite marked. The Irish workers Delaney and Donnelly (4) reported a similar spectacular improvement in flux rate with 95 percent demineralized cheese whey.

REASONS FOR FLUX RATE IMPROVEMENT

The findings of Hayes and coworkers (6) highlighted the importance of interactions between the higher-molecular weight proteins in whey and β-lactoglobulin. They considered the acid soluble caseinlike proteins to be of particular significance in the interaction. Hickey[1] in further studies showed that (1) β-lactoglobulin has a dominant influence on UF flux rates and (2) that on heating mixtures of β-lactoglobulin and bovine serum albumin (BSA) in whey dialysates, the pattern of ultrafiltration rates in relation to pH were similar to those of heated whey itself.

BSA and the caseinlike proteins elute in the same (first) peak when whey proteins are fractionated on Sephadex G100. Further study would be needed to be sure whether only one or both types of protein are involved but it is certainly clear that the aggregation fostered by heating and pH adjustment will overcome the tendency for whey to foul a UF membrane.

Flow Velocity

All UF plants aim for a flow pattern of the liquid which gives high shearing forces near the membrane surface. Earlier studies on whey showed limited benefit in commercial plants from increasing the flow velocity. However, the effect was more marked during UF of skim milk--a material which has little tendency to foul UF membranes.

---

[1] W. M. Hickey, Personal communication, 1976.

As may be seen from Figure 1 (from Marshall, Muller and MacBean)[2], the effect is also more marked with pretreated whey as compared with pasteurized whey, at least in a tubular UF plant. Several UF plant manufacturers are now providing for higher flow velocities.

The combined effect of whey pretreatments and using plants which provide high shearing forces at the membrane surface have now reduced the cost of ultrafiltration.

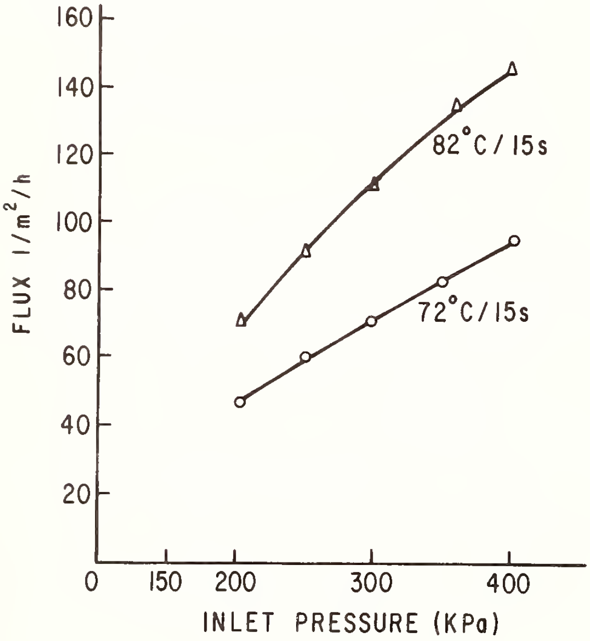


Figure 1.--Effect of inlet pressure on flux rate during ultrafiltration in Abcor HFA180 tubular modules. Flow velocity-4.3m/s; flow rate-127 l/min/tube; Cheddar cheese whey pretreated at 82°C/15s or pasteurized at 72°C/15s.

Figure 2 from Muller (8), gives an indication of the effects on UF costs per tonne of solids in liquid, 50 percent protein, WPC in a plant with 300,000 l/day whey capacity. Capital costs were included at the rate of 25 percent to cover interest and depreciation. The reduction in costs was mainly due to the high efficiency--a much smaller plant was needed to perform a given duty. However, there were other savings such as in membrane replacement costs--the membrane area needed was considerably reduced--and in cleaning and sanitation costs through reducing the deposits on the membranes.

It was, therefore, considered that UF could now be regarded as a satisfactorily economic process for Australian conditions.

PROPERTIES AND USES OF WPC

The pretreatments of whey which involve heating do, of course, partly denature the whey proteins and so alter their functional properties and

---

[2] S. C. Marshall, L. L. Muller, and R. D. MacBean. Personal communication, 1976.

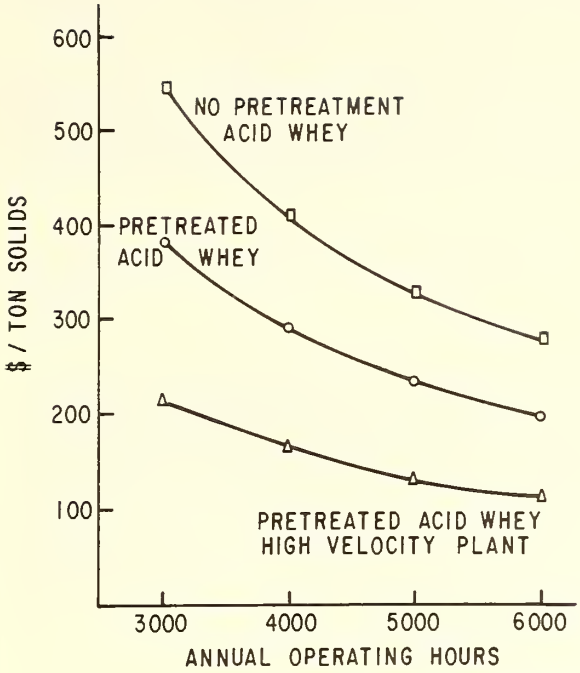


Figure 2.--Effect of pretreatment of acid whey and use of high velocity ultrafiltration plant on estimated cost of producing whey protein concentrate (liquid, protein = 50% of solids), maximum plant capacity 300,0001/day.

potential end-use applications to some extent. This aspect is being examined at present. Muller (8) gave a brief outline of this progress. The extra whiteness of the WPC from pretreated whey could be considered an advantage in some applications. For applications where clear solutions or fully undenatured whey proteins are required, demineralization of the whey can be considered provided the cost of demineralization can be largely recovered through the lactose products. Alternatively, normally treated whey can be processed at periods of the year when surplus UF plant capacity is available. The WPC product range can, therefore, be as broad as desired.

One promising application for WPC studied in detail by Stewart, Muller, and Griffin (14) is its use in manufacture of calf milk replacers (CMR). A CMR based on WPC was shown to be as good for calf rearing as CMR based on nonfat milk solids.

REVERSE OSMOSIS

The total economics of manufacturing whey products depend on the interrelationships of various processes. For example, as already mentioned, demineralization of whey improves UF performance and gives as ultrafiltrate a relatively pure lactose solution. If the ultrafiltrate is then partly concentrated by reverse osmosis (RO) more impurities can be removed in the permeate. At the same time, Peeler and Sitnai (12) showed that some savings can be made, compared with evaporation, in the cost of water removal.

RO can play an important role, therefore, in an overall whey utilization process as well as having uses in concentration of whey either for transport purposes or to boost evaporator capacity.

For these reasons RO has been studied in some detail. Smith and MacBean[3] experimented on type of whey or ultrafiltrate and pretreatment on RO performance. They have found that the flux rate for most wheys falls off with time according to the exponential model:

$J_t = J_o \, . \, t^{-b}$ where J_t is flux at time t and b is a constant. Deionized whey follows a linear model: $J_t = J_o - b.^1t$

In laboratory experiments, Hickey[4] found that the pretreatment of whey designed to cause interaction of the higher molecular-weight proteins and β-lactoglobulin and so increase UF performance actually decreased RO performance. Smith and MacBean[3] found the same in pilot-scale experiments.

RO performance is best on ultrafiltrate, particularly on demineralized ultrafiltrate.

PRODUCTS FROM ULTRAFILTRATE

Complete utilization of whey necessitates economic conversion of the ultrafiltrate into suitable products. A number of possibilities for this have been examined.

Results of preliminary feasibility studies have led the collaborating research workers to give first priority to a few processes that may have potential under Australian conditions.

LACTOSE

Australia does not manufacture lactose at present and this is likely to remain the case unless something can be done to reduce the high capital costs of conventional processes. Thurlby (15), with this in mind, examined crystallization kinetics and Thurlby and Sitnai (16) investigated some process alternatives. Their findings indicate that there was potential for reducing the capital costs associated with long crystallization times. The other factor that increases capital costs per tonne in a conventional process is the relatively low percentage recovery of the lactose from whole whey.

With combinations of various types of whey and pretreatment, the percentage of lactose in the solids of ultrafiltrate can range from about 81 to 99 (8). Our current programme, therefore, includes a study of the effect of the type of ultrafiltrate on the crystallization process, lactose recovery, and overall costs. More time is needed before it is known whether the efficiency of lactose production can be increased sufficiently for this product to be manufactured economically in Australia.

---

[3] B. R. Smith and R. D. MacBean. Personal communication, 1976.
[4] See footnote 1.

Lactose Hydrolysates

Another potentially important group of products can arise from hydrolysis of lactose to glucose and galactose. There are several methods for doing this using either enzymes or acid. The ones that seem to fit in best with the overall approach to whey utilization would be: (1) to use a UF plant as an enzyme reactor or (2) to use an ion-exchange plant for full or partial demineralization in conjunction with an acid hydrolysis reactor.

As other workers are studying the enzyme techniques, it was decided to give priority in the collaborative research programme to the acid hydrolysis technique.

Progress results[5] are encouraging enough to suggest that making of glucose-galactose syrups at a cost in the region of the Australian price for sucrose should be possible. The sweetener market is large. The ice cream, confectionery, and canned fruits industries could adsorb substantial amounts if quality, functional properties, and price are satisfactory. Tweedie and MacBean (17) have already shown that the syrups can be used to replace up to half the sucrose in canned peaches and pears without any commercially important effects on quality.

FERMENTATION PRODUCTS

Lactic Acid

Another phase of the research programme is on the manufacture of lactic acid, a product which from an earlier design and cost study (2) appeared to have good potential. This is being studied from two aspects to decreasing manufacturing costs. The first aspect involves improving fermentation efficiency through choice of optimum conditions and supplements (3) and the second, to reduce the cost of recovering lactic acid by applying the other membrane process, reverse osmosis, to the task. Figure 3 (13) illustrates the principle involved. At the usual pH of fermentation, rejection of lactose by the RO membrane is high but rejection of lactic acid is lower so that acid can be progressively removed from the system.

Yeast

Yeast production from ultrafiltrate is quite feasible and yeast for food uses tends to be in short supply in Australia. If the economics of production can be improved by one or other of the techniques being explored in Australia or overseas, yeast production may prove to have a useful role. At this stage, however, higher priority is being given to the studies on lactose hydrolysis and lactic acid manufacture.

---

[5] R. D. MacBean. Personal communication, 1976.

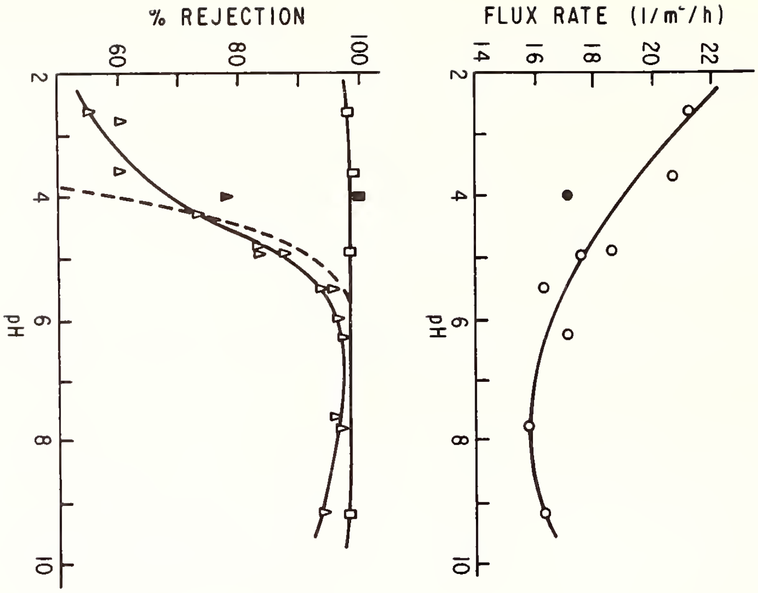


Figure 3.--Reverse osmosis with PCI T2/15 membranes. The effect of pH on the flux rates of model soutions (o) and ultrafiltrate fermentation liquor (●); on the rejection of lactose in model soution (▯) and ultrafiltrate fermentation liquor (▮) and on the rejection of lactic acid in model soutions (Δ) and in ultrafiltrate fermentation liquor (▲). The dissociation curve for lactic acid is drawn as a dashed line.

Animal Foods

The use of lick blocks from ultrafiltrate is being studied by the Victorian Department of Agriculture. Similar products have been made in the past from whey in the United States and from molasses in Australia. These blocks offer considerable potential as a palatable source of energy and of added trace components to meet specific animal dietary deficiencies. Their manufacture is relatively simple and not too costly in relation to potential market value.

CONCLUSION

Time has not permitted me to cover the programme completely. Studies on functional properties of protein concentrates received little mention and I have omitted such references as that of Zadow and Hill (18) which was one of several covering a study of the precipitation of whey proteins by carboxymethyl cellulose. The studies chosen for more detailed discussion were those which I believe illustrate best the approach to the main tasks to make whey utilization economically possible in Australia.

Only time will tell whether our approach will provide the answers in commercial application.

LITERATURE CITED

(1) Anonymous. 1974. Tackling the whey problem. Rural Res. 84: 2.

(2) Cable, P., and Sitnai, O. 1971. The manufacture of lactic acid by the fermentation of whey: a design and cost study. Rep: Div. Chem. Eng.; CSIRO, No. CE/R28, 28 pp. CSIRO Division of Chemical Engineering, Clayton, Victoria, Australia. 28 pp.

(3) Cox, G. C., and MacBean, R. D. 1976. Lactic acid production by Lactobacillus bulgaricus in supplemented whey ultrafiltrate. Aust. J. Dairy Technol. (In press.)

(4) Delaney, R. A. M., and Donnelly, J. K. 1975. International symposium "Separation processes by membranes, ion exchange and freeze concentration in the food industry" Paris, March 13-14.

(5) Hacquoil, A. E. 1972. The role of the dairy industry in environment pollution control. I. Control of pollution. Aust. J. Dairy Technol. 27: 123.

(6) Hayes, J. F., Dunkerley, J. A., Muller, L. L., and Griffin, A. T. 1974. Studies on whey processing by ultrafiltration II. Improving permeation rates by preventing fouling. Aust. J. Dairy Technol. 29: 132.

(7) Muller, L. L. 1972. The role of the dairy industry in environment pollution control. II. Whey utilization. Aust. J. Dairy Technol. 27: 125.

(8) Muller, L. L. 1976. Whey utilization in Australia. Aust. J. Dairy Technol. 31: 3 (In press.)

(9) Muller, L. L., Hayes, J. F., and Griffin, A. T. 1973. Studies on whey processing by ultrafiltration: I. Comparative performance of various ultrafiltration modules on whey from hydrochloric acid casein and Cheddar cheese. Aust. J. Dairy Technol. 28: 70.

(10) Oborn, R., Peeler, J. P. K., Piggott, K. L., and Sitnai, O. 1970. Whey utilization: A cost comparison of food processes for manufacturing whey products in Australia. Rep. Div. Chem. Eng.; CSIRO, No CE/R-23. 36 pp.

(11) Oborn, R., and Piggott, K. L. 1968. A review of methods available for whey utilization in Australia. Aust. J. Dairy Technol. 23: 131.

(12) Peeler, J. P. K., and Sitnai, O. 1974. Reverse osmosis concentration of carbohydrate solutions: process modelling and costing. J. Food Sci. 39: 744.

(13) Smith, B. R., MacBean, R. D., and Cox, G. C. 1976. The separation of lactic acid from lactose fermentation liquors by reverse osmosis. Aust. J. Dairy Technol. (In press.)

(14) Stewart, J. A., Muller, L. L., and Griffin, A. T. 1974. Use of whey solids in calf feeding. Aust. J. Dairy Technol. 29: 53.

(15) Thurlby, J. A. 1976. Crystallization kinetics of alpha lactose. J. Food Sci. 41: 38.

(16) Thurlby, J. A., and Sitnai, O. 1976. Lactose crystallization: investigation of some process alternatives. J. Food Sci. 41: 43.

(17) Tweedie, Leigh S., and MacBean, R. D. 1976. The effect of partial replacement of sucrose syrup by hydrolysed whey lactose on the quality of canned peaches and pears. Food Technol in Aust.

(18) Zadow, J. G., and Hill, R. D. 1975. The precipitation of proteins by carboxymethyl cellulose. J. Dairy Res. 42: 267.

WHEY PROCESSING IN NEW ZEALAND

K. R. MARSHALL

New Zealand Dairy Research Institute
Palmerston North, New Zealand

New Zealand, as a relatively large producer of cheese and casein, faces the problem common to all dairying countries of utilizing or disposing large quantities of whey in such a way to ensure the maximum economic return for the farmer and the minimum adverse effect on the environment.

To obtain a correct perspective of whey processing in New Zealand, it is essential to appreciate a number of the characteristics of the dairy industry in this country. These characteristics can be summarized under the following categories:

1. Export orientation.
2. Cooperative nature.
3. Processing facilities--size and versatility.
4. Seasonal production.

EXPORT ORIENTATION

New Zealand, a relatively small dairying country produces only about 6 million tonnes (tons) of milk per year, compared with a worldwide production of 400 million tonnes. However, New Zealand's population is also relatively small (3.1 million people). Some 85 percent of the milk produced in New Zealand is, therefore, processed for export. Of the worldwide production of 400 million tonnes, less than 4 percent is sold by international trade, of which New Zealand provides more than one-third. This international dairy trade is subject to sharp variations due to climatic, political, and economic changes, and small percentage fluctuations in worldwide milk production have a dramatic effect on the New Zealand dairy industry. As the dairy industry is responsible for about 20 percent of New Zealand's overseas earnings, New Zealanders are dependent upon adequate international prices for dairy products to maintain their standard of living. Under such conditions, it is not possible for New Zealand to afford export subsidies on dairy products. New Zealand's 17,500 dairy farmers are entirely dependent on efficient production and processing and adequate export returns for their livelihood.

COOPERATIVES

The dairy industry is based almost entirely on the cooperative principle. Factories are operated by 70 companies, whose shareholders are the farmers who supply the milk. Earnings are distributed by each company on the basis of the quality of milkfat supplied. All products manufactured for export are purchased by a centralized organization, the New Zealand Dairy Board, which is responsible for the international marketing of all dairy products. The Government-operated Dairy Division is responsible for quality control of all dairy products and dairy manufacturing units. The industry, with a Government subsidy, operates the New Zealand Dairy Research Institute as a centralized research and development laboratory.

PROCESSING FACILITIES

There are 116 factories operated by the 70 companies. The companies, generally, operate manufacturing units which allow considerable flexibility in the choice of products. Over half the milk processed in New Zealand is received by companies equipped to manufacture butter, cheese, spray-dried powders, and casein or its derivatives, and a further 25 percent is processed by companies lacking only cheesemaking facilities. Some of the companies are very large and about 75 percent of the milk is processed by only 13 companies. One of the strengths of the New Zealand industry is its ability to manufacture a diverse range of products with the flexibility to rapidly modify the product-mix as required.

SEASONAL PRODUCTION

A feature of the New Zealand industry, in common with those of Australia and Ireland, is the seasonal production pattern. The dairy herd feeds almost entirely on pastures of grass and clover, supplemented when necessary, with hay or silage. Calving is arranged to make the maximum use of the available pasture production. Virtually all cows calve in the late winter or early spring (July and August); milk production reaches a peak in early summer (October-November) and then declines until the cows are dried-off in early winter. This results in a highly variable milk flow to the dairy factory (Figure 1).

These characteristics of the dairy industry have a profound effect on whey processing in New Zealand. The dependence on overseas sales of dairy products for a high proportion of our overseas income, together with the need to be highly flexible so as to rapidly alter the product-mix to gain the maximum return in a volatile market can result in large fluctuations in the quantities of various products produced in any season. Thus, when casein prices are high relative to those for nonfat dried milk, the production of casein increases and vice-versa. If the price for cheese is depressed, cheese production decreases. These swings in production at the whim of the international market have tended to cause instability, particularly in casein production. There are indications that these swings will be less in the future and a minimum stable casein production will be maintained. This will give a greater incentive to establish whey processing, particularly for casein whey.

The seasonal production also has a limiting effect on whey processing. Available operating time at full capacity is only about 3,500 hours. Whey products, in general, have a low yield and the capital costs for equipment are high.

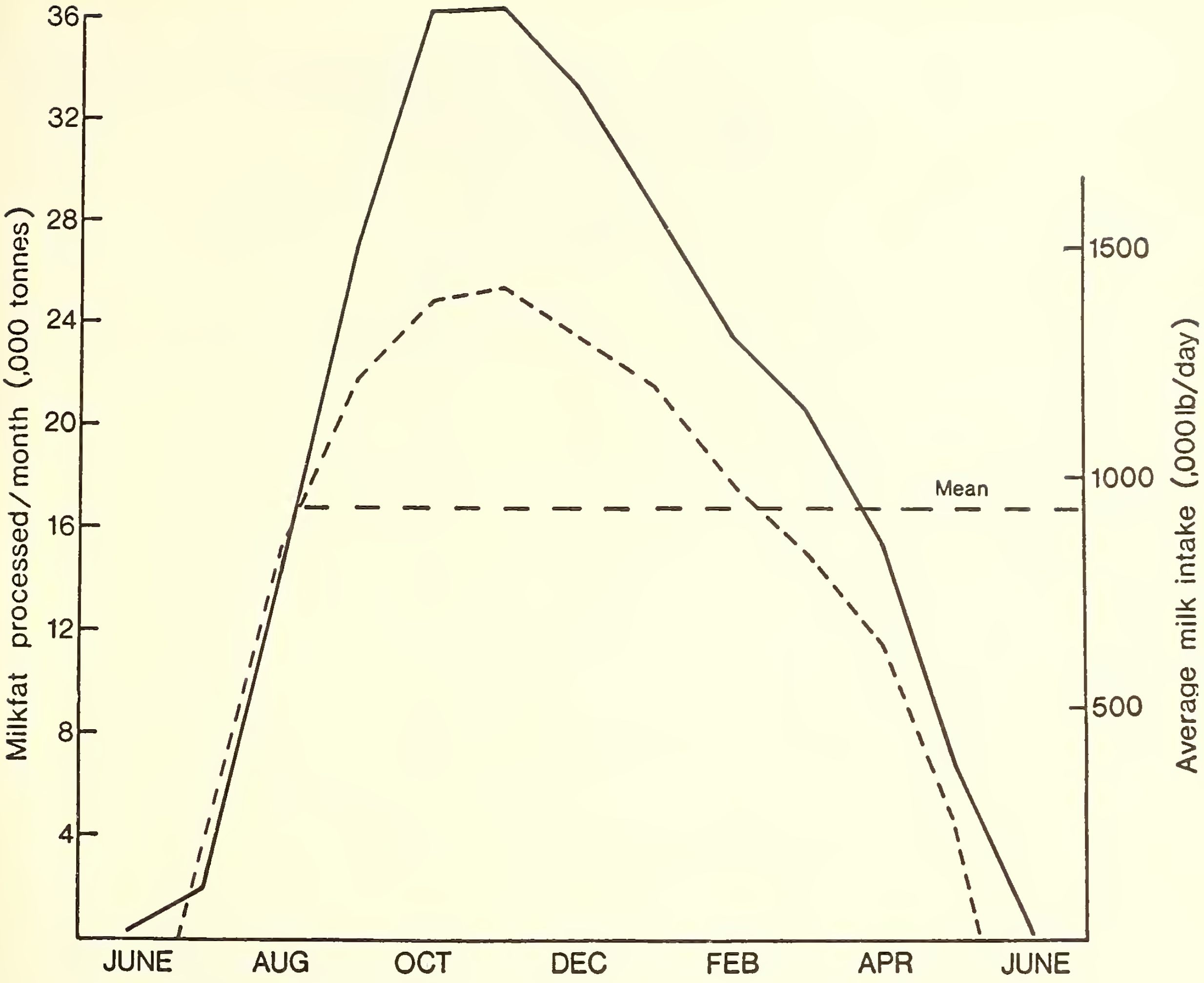


Figure 1.--Milkfat processed per month in New Zealand (———) and the average daily milk intake to a typical factory (-----) during 1974-75.

The resulting relatively low potential of return because of high capital and interest charges have been a disincentive to establishing sophisticated processing. Two other factors have not favored more development of whey processing: (1) the ready availability of a suitable disposal method, particularly spray irrigation and (2) the difficulty of processing acid whey.

PRODUCTION STATISTICS

The annual production in New Zealand of cheese, casein, and caseinates since 1965 is shown in Table I. The main variety of cheese is Cheddar, but increasing quantities of Egmont, Cheshire, and Gouda are being manufactured. The production of Mozzarella and Fetta has begun on a limited scale. Cottage cheese production is insignificant. Two types of casein are produced: (1) acid casein, in which pasteurized skim milk is inoculated with a suitable lactic culture and incubated until the pH is 4.5. The coagulum is then cooked and separated from the whey. (2) Rennet casein, in which a clot is formed in skim milk by the addition of rennin.

TABLE I.--New Zealand statistics of commodities which have whey as byproduct

Year ended	Cheese	Casein		Caseinates
		Acid	Rennet	
	Tonnes			
1965-66	107,388	51,571	2,281	---
1970-71	107,849	48,068	7,562	---
1971-72	104,298	35,563	4,703	---
1972-73	101,105	34,850	6,400	740
1973-74	89,032	30,139	5,126	1,020
1974-75	88,609	29,512	3,897	1,084
1975-76	103,000	44,500	4,500	3,800

Source: New Zealand Dairy Board Annual Reports.

The variations in annual production illustrate the industry's versatility and dependence on the export market. Both cheese and casein production fell in the 1973-75 dairy seasons when the returns encouraged the maximum production of nonfat dried milk. As the international price for milk powder fell during 1975, so the production of cheese and casein increased. This trend will continue for 1976 as will the increasing production of casein derivatives.

Based on the assumption that the manufacture of 1 tonne of cheese produces 7.6 tonnes of whey, and 1 tonne of casein, 25 tonnes of whey, the quantities of whey produced in New Zealand during the 1975-76 dairying season are shown in Table II.

As with the dairy industries in other countries, the number of cheese factories in New Zealand has fallen steadily over the past decade until now there are 52. This has occurred mainly as the result of company amalgamations with the result that the average quantity of cheese (and hence whey) produced per factory has almost doubled (Figure 2) to 1,700 tonnes per year. There are many small cheese factories, and thus the largest factories are capable of producing over 5,000 tonnes of cheese per year, that is, over 350 tonnes per day of whey. The number of casein companies has stayed relatively constant over the past decade, falling from 26 in 1965 to 22 in 1975. Some of the casein factories are large, a number being capable of processing more than 500 tonnes of milk per day. Thus, there is sufficient whey (both cheese or casein) available in one location to make whey processing potentially a practical possibility.

TABLE II.--Estimated quantities of liquid whey produced in New Zealand in 1975-76

Item	Tonnes
Cheese	780,000
Acid casein	1,208,000
Rennet casein	113,000

Note: Estimated assuming 7.6 tonnes whey/tonne of cheese and 25 tonnes whey/tonne casein.

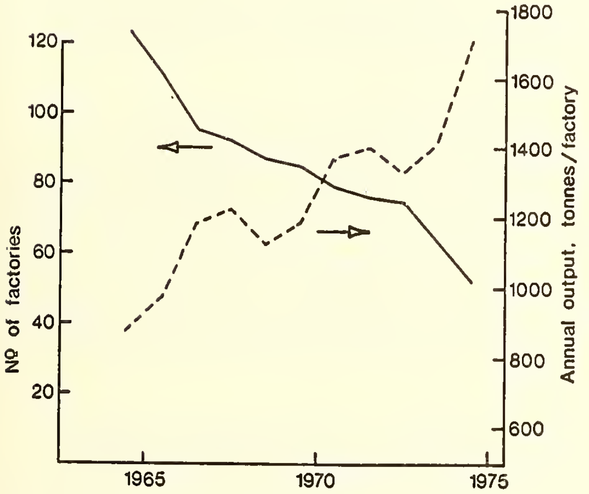


Figure 2.--The number of cheese factories(———) in New Zealand has decreased dramatically in the last decade. The average production per factory (-----) has almost doubled.

WHEY PRODUCTS

The production statistics for whey products in New Zealand for the past 2 years are shown in Table III. Whey from over 40 percent of the cheese produced in New Zealand is purchased by the Lactose Company of New Zealand (a subsidiary of the British Unigate Group) and converted into lactose, delactosed whey powder, and stock foods. The whey is collected from the cooperative cheese factories and tankered to the processing plant.

TABLE III.--Manufacture of whey products in New Zealand

Item	Tonnes 1974-75	1975-76
Lactose	7,500	9,400
Whey butter	2,727	3,040
Lactalbumin		170
Rennet whey powder	1,378	2,900
Cheese whey powder		500
Delactosed whey powder		860
Infant foods	6,673	17,000

Source: New Zealand Dairy Board Annual Reports.

Whey butter is manufactured from the cream separated from cheese whey, a practice adopted by all cheese companies in New Zealand.

Lactalbumin, produced by heat precipitation of the whey proteins followed by recovery, washing, and drying, has been manufactured in New Zealand for over 20 years[1]. Production capacity is expected to increase. Soluble whey protein is produced by two companies. This process was discussed at the 1972 Whey Products Conference[2].

Rennet whey powder, with its relatively low ash content, is a suitable ingredient for foodstuffs, particularly infant foods, and is being produced in increasing quantities in New Zealand.

Only small quantities of dried cheese whey powder have been produced, particularly for export. World prices have not justified the costs of manufacture and transport to markets.

An increasing quantity of formulated infant foods is being manufactured in New Zealand. Some of these formulations contain whey solids, a portion of which have been demineralized.

---

[1] Robinson, B. P., Short, J. L., and Marshall, K. R. 1976. New Zeal. J. Dairy Sci. Technol. 11: 114.

[2] Horton, B. S., and Kirkpatrick, K. J. 1973. In Proceedings Whey Products Conference, Chicago, Ill, June 14-15, 1972. U.S. Dept. Agr., Agr. Res. Serv. ERRL Pub. 3779, p.131.

About 30 percent of the cheese and casein whey produced in New Zealand in 1972 was returned to the farms as food for pigs. However, this practice is declining because of the difficulties created by the low solids content of the whey and the variable supply, both seasonal and as a result of diversions to other products in accordance with market returns. Attempts to store the whey, either concentrated or with added preservative, have met with only limited acceptance.

Large quantities of lactic whey are disposed of as effluent either by disposal to a waterway or by spray-irrigation. The former is becoming less common in New Zealand, although legislation, based on acceptable standards for receiving waters, can permit discharge of whey to large bodies of water. Spray-irrigation to dispose of whey is used by 12 companies and if properly controlled, is an effective method which gives benefits to both factory and farm. Whey is irrigated for most of the dairying season at up to 100 m^3/ha/dose (i.e., an average of 7 m^3/ha/day when the return cycle is 14 days) without harm to the pasture. In fact, pasture growth is enhanced and no other fertilizer is required[3].

In general, cheese and rennet casein wheys are being fully utilized in New Zealand. In some instances, the demand for these wheys exceeds supply. Lactic casein whey, however, is little used except for the production of lactalbumin. The high acidity (pH 4.5), reduced lactose content (4.2 percent _cf_. 5.0 percent for cheese whey) and high ash concentration (0.72 percent _cf_. 0.50 percent for cheese whey) have handicapped the commercial exploitation of this acid whey.

There is an increasing awareness in New Zealand that a stable dairy industry requires the economic processing of all the solids from the milk. Casein whey represents the only portion of the milk with the potential to make a significant improvement in returns to the dairy farmer from processing. The advent of environmental legislation is further heightening the awareness of the need to process casein whey. In the last decade significant research effort has been directed towards promoting its efficient utilization.

WHEY RESEARCH

Whey utilization has been studied in New Zealand in a number of laboratories. I will present a portion of the research work being undertaken in the New Zealand Dairy Research Institute.

The main aim of the group at the Institute is to provide the New Zealand dairy industry with the information required to establish economical methods of whey processing. The group has available facilities for the following unit operations: Centrifugation (separating and clarifying); filtration, ultrafiltration, reverse osmosis, ion-exchange, electrodialysis, evaporation (falling-film and swept-surface) drying (spray disc or nozzles, drum, freeze, and vacuum), and fermentation. There are pilot-scale facilities for the manufacture of almost any dairy product, with the result that whey can be produced when required, under controlled conditions. Laboratory facilities are also available for both chemical and microbiological analyses.

---

[3] Parkin, M. F., and Marshall, K. R. 1976. New Zeal. J. Dairy Sci. Technol. 11: 196.

Since 1969, the Institute has made an extensive study of the production, properties, and uses of soluble whey protein manufactured by the ultrafiltration of lactic casein whey. Initial work was aimed at finding the most practical conditions of operation to retain whey protein functionality with maximum yield and with minimum microbial contamination of the final product. This led to defining suitable operating, cleaning, and sanitizing methods for commercial operation.

Table IV shows a comparison of pilot plants from a number of manufacturers. Table V shows data on average flux and protein rejection. Fluxes ranged from 28 $l/m^2/h$ for the PCI and Romicon modules to 50 $l/m^2/h$ for the Dorr-Oliver, although it should be noted that the latter is from only a limited number of trials. Also, this high flux was achieved at the expense of a lower rejection of protein (protein is (Kjeldahl total nitrogen - nonprotein nitrogen) x 6.38) of 0.96, whereas the value was 0.98 or greater for the other modules. While a direct comparison of flux and rejection data from ultrafiltration pilot plants is important, other factors such as the capital cost, membrane replacement costs, microbiological quality of concentrates and ultrafiltrates, cleaning, sanitizing, after-sales service, and compliance with health and hygiene regulations must also be taken into account. Many of these factors cannot be accurately assessed with small pilot plants.

TABLE IV.--Operating conditions of ultrafiltration pilot-plants. All experiments involved batch concentrations of lactic casein whey protein for up to 20 h at 49°C

Manufacturer[1]	Membrane	Average pressure kPa	Recirculation rate l/s
Abcor	Tubular, HFA180	220	2.6
DDS	Sheet, Type 600	450	0.53/section
Dorr-Oliver	Cartridge, XP24	276	6.3
PCI	Tubular, T5/4	435	0.33
Romicon	Fibre, HF26.5-45-XM50	126	(170 kPa)[2]

[1] Abcor Inc., Wilmington, Mass.
De Danske Sukkerfabrikker (DDS), Denmark.
Dorr-Oliver Pty, Stamford, Conn.
Paterson-Candy International (PCI), London.
Romicon, Woburn, Mass.

[2] Inlet pressure.

TABLE V.--Ultrafiltration of lactic casein whey in pilot scale equipment, average flux and protein rejection in batch operation to give protein concentrations in the range 8 to 14 percent

Item	l/m^2 h	Protein rejection
Abcor	47	0.985
DDS	48	.982
Dorr-Oliver	50	.959
PCI	28	.980
Romicon	28	.990

The most recently acquired item of equipment in our laboratory is a four-stage ultrafiltration unit, designed to operate in the continuous mode. The unit is fitted with Abcor HFM-180 noncellulosic membranes with resin-impregnated fiberglass backings, with a membrane surface area of 3.68 m^2/stage, a total of 14.7 m^2. Within each stage, average pressure, temperature, and recirculation flow-rate can be controlled. The permeate from each stage can be separately monitored and collected. The predicted residence time of protein in the unit is 1.8 to 2.0 h when effecting a 20:1 volume reduction. The unit is providing useful experience in operation in continuous mode and is being used to further study some of the fundamentals of ultrafiltration.

Soluble whey protein powders (Solac) containing 35 to 85 percent protein have been prepared from lactic casein whey. Solac has been shown to be a high quality protein (PER 3.2 cf. casein 2.5) with good solubility over the pH range of interest to food processors. Solutions of whey protein concentrates containing 10 percent protein give firm gels when heated at 72° to 85°C. The temperature of gelling is a function of the preheat temperature, protein level of the Solac, pH of the solution, the concentration of calcium, and the presence of other additives. Solutions of Solac also form stable whips and detailed studies have been made of this characteristic. Lipid contents greater than 3 percent (dry-basis) adversely affect whipping. Heat treatment (55°C per 3 min) of solutions of Cheddar cheese whey protein concentrates was necessary to obtain reasonable whips. If the initial whey was clarified after pasteurization before ultrafiltration, the resultant cheese whey protein concentrates possessed better whipping abilities than the unclarified products. Similar results were not obtained with casein whey, presumably because of the lower lipid content of the latter. It is of interest to potential users of Solac to note that refrigeration of solutions of whey protein concentrates before adjusting to whipping temperature adversely affected their whipping ability.

Solacs have been incorporated into a wide range of foodstuffs, particularly as a protein supplement. Beverages containing protein at concentrations up to 3 percent over the pH range from 2.5 to 7.0 have been prepared at the

New Zealand Dairy Research Institute, although the practical upper level is probably about 1.5 percent for most products. Carbonated and noncarbonated acid fruit beverages were found to be organoleptically acceptable after 6 months' storage. The protein was also successfully incorporated into dry mix beverage formulations and fresh fruit juices. Confectionery, frozen desserts, biscuits, cakes and others have all been formulated. A wide range of products with high nutritional value but low in sodium and potassium has been formulated and prepared for incorporation in speciality pharmaceutical diets.

A number of reverse osmosis modules and membranes have been compared for the concentration of cheese whey (Table VI). Of particular interest are the PCI T2/40 and Abcor AS290X membranes which have a relatively high permeate flux, retain all protein, have a lactose rejection greater than 98 percent but show an ash rejection of about 73 percent. Thus, after a 4:1 concentration of Cheddar cheese whey, a 33 percent ash reduction in the concentrate was obtained. This has significant economic implications if, for example, further demineralization by electrodialysis is being considered.

The production of proteins from whey does not utilize the complete whey solids, and we have investigated potential uses for the remaining crude lactose solutions. Demineralization by ion-exchange removes the major contaminants, ash and lactate. If, after concentration to 45 to 50 percent total solids, the concentrate is held at 95°C for 10 minutes to allow muta-rotation of the lactose to the β-form, the lactose can be recovered as a nonhygroscopic powder with good flavor by drying on a twin-drum roller drier. The product is greater than 95 percent lactose. We are studying incorporation of the product into a range of foods[4].

TABLE VI.--Concentration (4:1) of Cheddar cheese whey by reverse osmosis

Manufacturer	Membrane	Average flux l/m^2 h	Yield of total solids, percent
PCI	T1/12	11	> 98
PCI	T2/15W	21	> 98
PCI	T2/40	23	> 93
DDS	985 1	19	> 96
Abcor	AS 290 X	29	> 93

---

[4] Kavanagh, J. A. 1975. New Zeal. J. Dairy Sci. Technol. 10: 132.

Ion-exchange has also been used to modify lactic casein whey so as to make it resemble rennet casein whey. Three columns were found to be desirable (strong acid, IR-120; mixed strong and weak base, IRA-402 and IRA-93; weak acid, IRC-50--all resins Rohm & Haas, Pa.). The acid column has a capacity of 11 l whey/l resin, while the anion column had a capacity of 5 l whey/l resin. The weak acid column was used to finally adjust the pH. Powders obtained had an ash composition similar to that of demineralized rennet whey, but the protein content was lower (12 percent cf. 16 percent for normal rennet casein whey powder).

Other studies have looked at the feasibility of hydrolysing the lactose in whey or deproteinated whey to its constituent sugars. Enzymatic and homogeneous and heterogeneous acid catalysis are all being investigated.

Yeast production has also been carried out on a pilot scale to convert the lactose to protein. Whey or deproteinated whey supplemented with ammonia, urea, magnesium, and the three vitamins, niacin, pantothenate, and biotin, were used to propagate Saccharomyces fragilis in a continuous fermentation at pH 3.5 and 38°C.

To cover the complete range of recent and present research topics in whey processing is not possible but, I hope I have given some idea of the extent of our studies and their orientation towards obtaining the information needed by the New Zealand dairy industry.

I have tried to give you some background to the New Zealand industry and outline how it has and will affect the future of whey processing. Though not yet utilizing all the available whey, particularly the acid type, a considerable research effort has been encouraged in New Zealand and this should lead to an even greater range of products being offered for sale, both within New Zealand and in the wider world market.

Because of the intense competition on the international market for such basic products as whey powder, emphasis has been placed on the use of technology and the production of the more sophisticated products.